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INTERNATIONAL GEOLOGICAL CONGRESS

twenty-fourth session

CANADA-1972

FIELD EXCURSION A03 - C03

GEOLOGY OF THE SOUTHERN CANADIAN CORDILLERA

GUIDEBOOK

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GUIDEBOOK

XXIV INTERNATIONAL GEOLOGICAL CONGRESS
Montreal, Quebec
1972

Excursions A03 - C03

GEOLOGY OF THE SOUTHERN CANADIAN CORDILLERA

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Geological Survey of Canada

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Guidebook Editor

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Canadian Export Gas & Oil Ltd.
Calgary

24th INTERNATIONAL GEOLOGICAL CONGRESS
601 Booth St.
Ottawa, K1A 0E8

$2.00

PRINTED BY
JOHN D. MCARA LIMITED, CALGARY

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Geology

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Idaho
117° EASTE

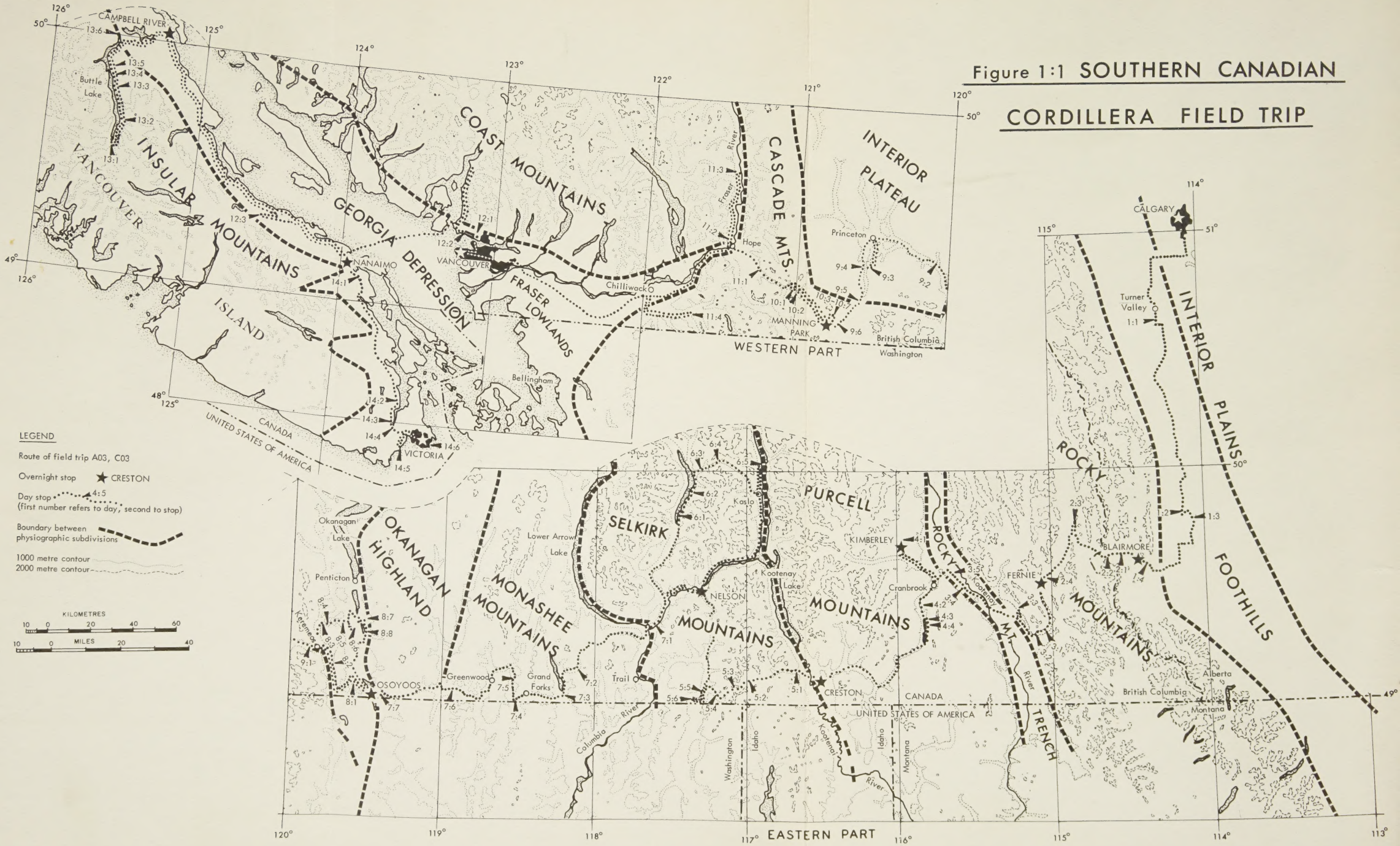


Figure 1:1 SOUTHERN CANADIAN
CORDILLERA FIELD TRIP
LEGEND
Route of field trip A03, C03
Overnight stop ★ CRESTON
Day stop 4:5
(first number refers to day, second to stop)
Boundary between physiographic subdivisions
1000 metre contour
2000 metre contour
KILOMETRES
MILES
CAMPBELL RIVER
Buttle Lake
VANCOUVER ISLAND
INSULAR MOUNTAINS
GEORGIA DEPRESSION
COAST MOUNTAINS
CASCADE MTS.
INTERIOR PLATEAU
NANAIMO
VANCOUVER
FRASER LOWLANDS
Chilliwack
Hope
Princeton
MANNING PARK
WESTERN PART
Bellingham
VICTORIA
CANADA
UNITED STATES OF AMERICA
CALGARY
Turner Valley
INTERIOR PLAINS
ROCKY MOUNTAIN FOOTHILLS
BLAIRMORE
FERNIE
ROCKY MOUNTAINS
Okanagan Lake
Penticton
Keremeos
OSOYOOS
OKANAGAN HIGHLAND
MONASHEE MOUNTAINS
Greenwood
Grand Forks
Trail
Lower Arrow Lake
SELKIRK MOUNTAINS
Kaslo
NELSON
Kootenay Lake
PURCELL MOUNTAINS
KIMBERLEY
Cranbrook
CRESTON
Columbia River
Kootenay River
MT. RIVER TRENCH
Alberta
British Columbia
Montana
Washington
Idaho
EASTERN PART

GEOLOGY OF THE SOUTHERN CANADIAN CORDILLERA

Preface

Excursion A03 is scheduled to start on August 5 in Calgary and to end August 19 in Victoria.

Excursion C03 is scheduled to start on August 31 in Calgary and to end September 13 in Victoria.

This field excursion along the southern transprovincial highway, drawing on the personal knowledge of many geologists who have worked recently in this part of the Cordillera, was conceived by J. W. Monger and V. A. Preto and will be under their direction throughout. The guidebook was compiled by them but contributions were made by eight other geologists as indicated. These geologists are responsible for the guidebook descriptions and the geological content of their part of the excursion.

Drafting of the text-figures was mainly by K. S. Crabtree and J. L. Armitage of the British Columbia Department of Mines and Petroleum Resources.

Introduction

This excursion deals with the geology along a cross-section of the southern Canadian Cordillera within one degree latitude of the Canada-U.S. border (Fig. 1:1). The excursion begins in Calgary, which is on the western edge of the Interior Plains, and ends in Victoria, covering a distance of approximately 1,100 miles (1,760 km). This part of the Canadian Cordillera is easily accessible, contains most of the major elements of the Cordillera, and geologically is relatively well-known. In addition, it is close to the area of the classical Boundary Survey by R. A. Daly (1912), which formed the basis for many of the theories subsequently propounded by him.

The Canadian segment of the North American Cordillera consists of, from east to west, predominantly sedimentary miogeosynclinal strata in the Rocky Mountain Belt, metamorphic and granitic rocks in the Omineca Crystalline Belt, unmetamorphosed and low-grade rocks in the Intermontane Belt, predominantly granitic rocks in the Coast Plutonic complex, and unmetamorphosed and low-grade sedimentary and volcanic strata in the Insular Belt (Fig. 1:2b). It differs

in several ways from the segment to the south in the United States. Firstly, in the United States there appears to be only one crystalline belt, comprising the Sierra Nevada granitic complex and associated metamorphic rocks, although the Cenozoic cover (Fig. 1:2a) conceals much of the critical transition zone in the northwest. The geosynclinal belt south of about latitude 47° appears to correspond to the Canadian Rockies, Omineca Crystalline Belt and the Interior Belt. Tectonic elements analogous to the Canadian Coast Plutonic complex and Insular Belt are not represented. Secondly, the block-faulted Central Rockies of Colorado and the Colorado Plateau with its thin sedimentary veneer have no counterpart north of latitude 47°N. Thirdly, exposures of pre-Cenozoic sedimentary and volcanic strata are more extensive in Canada. Finally, the regional trend is rectilinear instead of the complex "z-shaped" pattern to the south (*see* Wise, 1963). The excursion is in the transition zone between the typical Canadian Cordillera and the United States segment.

Physiography and Glaciation — The physiographic subdivisions reviewed below from east to west are taken from Holland (1964). Their distribution within the Cordillera is shown approximately in Fig. 1:2c, in more detail at the latitude of the trip in Fig. 1:1, and their relationship to structural elements and bedrock in Fig. 1:3. The extent of Wisconsin and Recent ice, which has had a considerable effect on topography in this part of the Cordillera, is shown in Fig. 1:4.

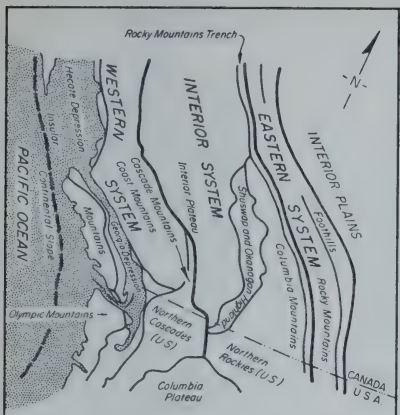
(1) Interior Plains

The Interior Plains are flat lying or gently rolling with locally incised drainage developed on undeformed upper Mesozoic and Tertiary sandstones and shales. The elevation of the Plains increases toward the mountains and at their western edge near Calgary is about 3,500 feet (1,070 m).

(2) Canadian Cordillera

The Canadian Cordillera comprises the Eastern, Interior and Western systems, subdivided into mountain, plateau or trough areas. All of these areas are well represented at the latitude of this excursion except for the Interior Plateau, which is here very narrow and can be barely differentiated from the mountain areas on either side (Fig. 1:1, 1:2c). South of the 49th Parallel it is absent.

Fig. 1:2. Regional geological elements of the North American Cordillera; **a.** Geological framework; **b.** Major structural elements; **c.** Physiographic subdivisions.



BOUNDARIES BETWEEN SYSTEMS
BOUNDARIES WITHIN SYSTEMS

Figure 1:2c PHYSIOGRAPHIC SUBDIVISIONS

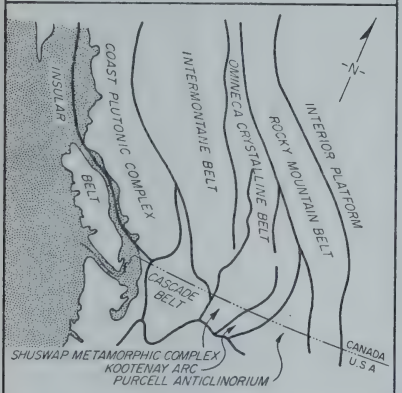


Figure 1:2b MAJOR STRUCTURAL ELEMENTS

Figure 1:2a GEOLOGICAL FRAMEWORK

- CENOZOIC VOLCANIC ROCKS.
- MAINLY PHANEROZOIC SEDIMENTARY ROCKS
- PHANEROZOIC SEDIMENTARY AND VOLCANIC ROCKS
- GRANITIC ROCKS (MAINLY MESOZOIC)
- METAMORPHIC ROCKS (MAINLY MESOZOIC)
- PRECAMBRIAN METAMORPHIC AND GRANITIC ROCKS
- EASTERN MARGIN OF CORDILLERAN OROGEN
- EASTERN LIMIT OF GEOSYNCLINAL DEPOSITS.
- BOUNDARY BETWEEN MIOGEOSYNCLINAL AND EUGEOSYNCLINAL DEPOSITS.

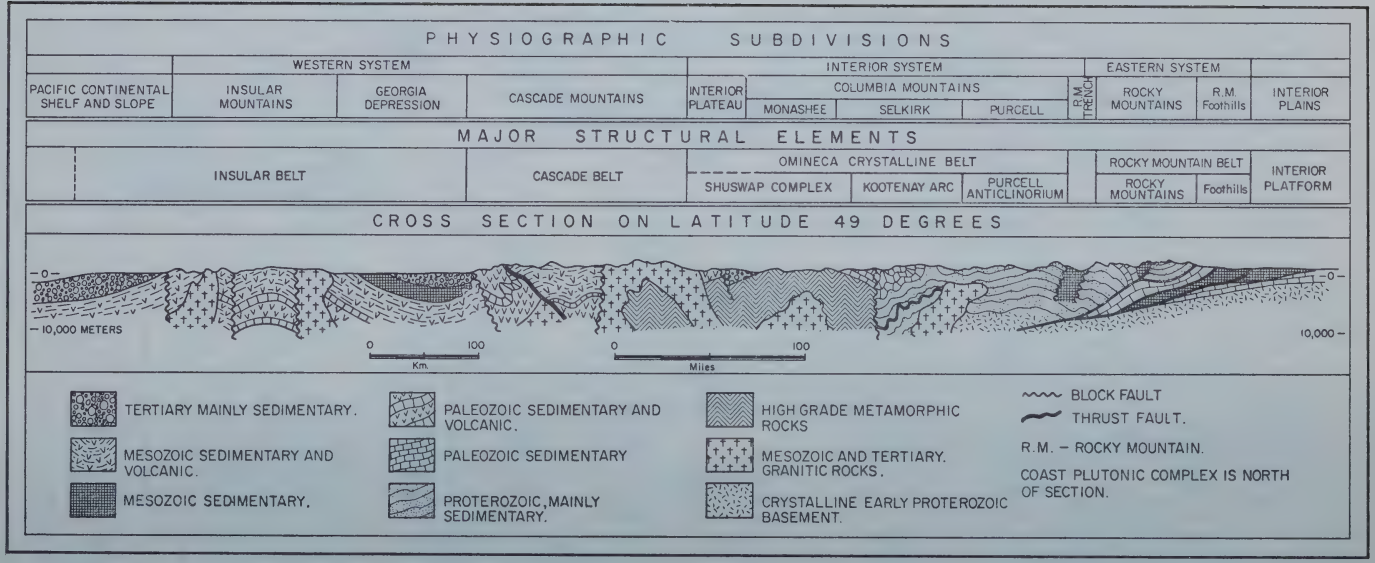


Fig. 1:3. Character of structural elements in the Canadian Cordillera andtheir relationship to physiographic subdivisions.

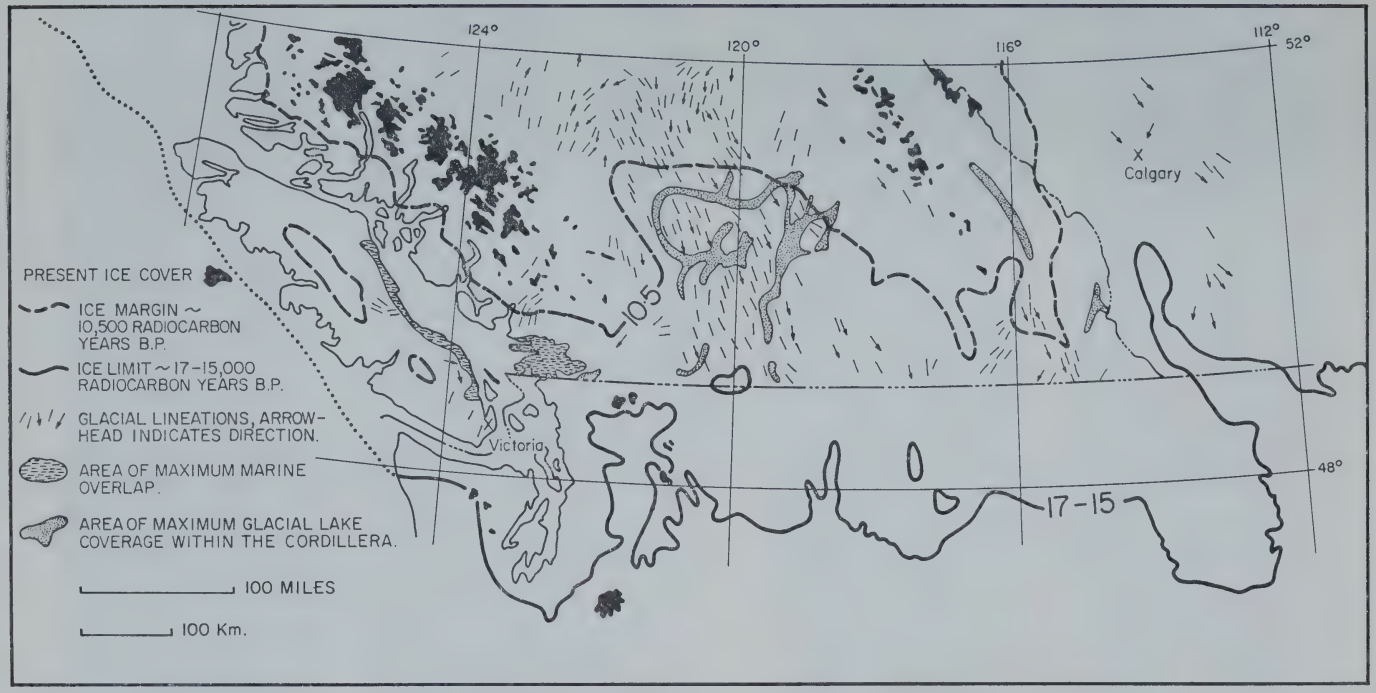


Fig. 1:4. Maximum extent of Wisconsin and present ice cover.

Eastern System

(i) Rocky Mountain Foothills

The eastern limit of the Cordillera is represented by the Rocky Mountain Foothills, a series of rounded northerly-trending ridges rising from the Interior Plains to elevations of about 6,000 feet (1,830 m). They are composed of thrust-faulted and folded Mesozoic sandstones and shales, with the more resistant sandstones forming the ridges.

(ii) Rocky Mountains

The Rocky Mountains rise like a wall out of the rolling Foothills, and form the most distictive physiographic unit on the field trip. Their characteristic layer-cake appearance is produced by alternating steep cliffs of thick, sheet-like Paleozoic carbonates and gentler slopes of recessive pelitic units. The whole sequence commonly dips gently and is repeated by thrust-faulting. The maximum elevation of the Rockies at this latitude is 11,000 feet (3,350 m) but the general summit level is approximately 9,000 feet (2,740 m).

Interior System

Whereas bedrock largely controls topography in the Eastern System, differential uplift and glaciation are probably the major controls of the landforms in the Interior System.

(i) Rocky Mountain Trench

At this latitude the Rocky Mountain Trench is a valley about 7 miles (11.2 km) wide, lying at an elevation between 2,500 and 3,000 feet (760 to 910 m). It is a tectonic valley modified by erosion and infilling, and forms the boundary between the Eastern and Interior Systems. In Canada it has a total length of 900 miles (1,450 km) and extends south of the International Boundary for at least 60 miles (96 km).

(ii) Columbia Mountains

The Columbia Mountains comprise, from east to west, the Purcell, Selkirk and Monashee Mountains. The Purcell Mountains are largely underlain by Proterozoic clastic rocks and carbonates, and are separated from the Selkirk and Monashee Mountains by the structurally-controlled, glacially-deepened Purcell Trench. In contrast to the Purcell Mountains, the Selkirk and Monashee Mountains are underlain by metamorphosed Proterozoic, Paleozoic and Mesozoic strata cut by numerous granitic intrusions (Fig. 1:3).

The Columbia Mountains have a somewhat uniform appearance regardless of the different underlying bedrock lithologies. Maximum summit elevations range between 7,000 and 9,000 feet (2,130 to 2,740 m) but are as much as 11,000 feet (3,350 m) north of the strip traversed. Below 8,000 feet (2,440 m) the mountains are characteristically rounded because of erosion by the Cordilleran ice sheet (Fig. 1:4), whereas the summits above this elevation are sharp peaks and ridges that projected above the ice sheet and were sculptured by Alpine glaciation.

(iii) Interior Plateau

At the latitude of the excursion, the Interior Plateau is a poorly defined transitional zone between the deeply dissected Columbia Mountains to the east and the Cascade Mountains to the west. The rolling, slightly to moderately dissected upland area to the north lying between 4,000 and 5,000 feet (1,220 to 1,520 m) (*see* Fig. 1:1) constitutes the true Interior Plateau. Of note is the deep, north-trending, structurally controlled Okanagan Valley where the floor at Osoyoos is only 1,000 feet (300 m) above sea-level.

Western System

(iv) Cascade Mountains

The Cascade Mountains in Canada are the northernmost extension of the Northern Cascades, the mountain chain that forms the major physiographic unit in the northwestern United States. They consist of deformed, variably metamorphosed upper Paleozoic and Mesozoic sedimentary and volcanic rocks, intruded by granitic plutons. Maximum summit elevations in Canada are between 7,000 and 9,000 feet (2,130 to 2,740 m). Mountains above 7,000 feet (2,130 m) are sharp and have been subjected to Alpine glaciation; the lower mountains were rounded by the Cordilleran ice sheet.

(v) Coast Mountains

The Coast Mountains are carved out of Mesozoic granitic plutons, which form probably the largest Phanerozoic granitic complex in the world, together with variably metamorphosed upper Paleozoic and Mesozoic strata that occur as septa between and enclosed by individual plutons. The physically homogeneous bedrock has a marked influence on topography. In places, massive granitic rock forms vertical cliffs or characteristic domes. Joints, faults and septa influence the drainage pattern and the orientation of the numerous fiords devel-

oped along the coast. At the latitude of the excursion, summit elevations are between 7,000 and 9,000 feet (2,130 to 2,740 m) although farther north summit elevations to 13,000 feet (3,960 m) are attained. The effects of glaciation are somewhat similar to those described for the Cascade Mountains.

(vi) Georgia Depression

The Georgia Depression is a structurally low area underlain by Upper Cretaceous, Tertiary and Quaternary strata. The Strait of Georgia, the main part of the Georgia Depression, is as much as 1,300 feet (400 m) deep. The Depression also includes the Fraser River delta between the Coast Mountains to the north and the Cascade Mountains to the southwest, and a low area as much as 10 miles (16 km) wide along the east coast of Vancouver Island.

(vii) Insular Mountains

The Insular Mountains of Vancouver Island are underlain by upper Paleozoic to Tertiary sedimentary and volcanic strata intruded by granitic plutons. The topography results from pre-Pleistocene uplift and dissection of a Tertiary erosion surface of low relief. Mountains are as much as 7,000 feet (2,130 m) high and except for some nunatak peaks they have been extensively modified by Pleistocene ice below 5,000 feet (1,520 m) in elevation.

Physiographic History — According to Mathews (1968, p. 19) the post-Middle Eocene, pre-Late Miocene upland of the Interior Plateau is the oldest physiographic surface preserved in the region today. Scattered relics of this upland may be preserved in the Coast and Cascade Mountains. During Pliocene and Pleistocene time there was differential uplift with increased stream erosion. A Pleistocene ice sheet, the surface of which was in places at a maximum elevation of 8,000 feet (2,440 m), covered most of British Columbia and reached its greatest extent 15,000 to 17,000 years ago (Fig. 1:4). Glacial deposits 30,000 to 60,000 years old are known at a few places in southern British Columbia, but the patterns of older glaciations are not known.

Glaciation led to a relative rise in sea level, and deglaciation produced complicated changes in sea level and in drainage patterns on the mainland. Terraces at about 650 feet (195 m) above sea level in North Vancouver and weathered clays 30 feet (10 m) below Victoria harbour are striking evidence of these changes in sea level. Terraces of outwash and glacial lake deposits along major valleys can be seen at a number of

places along the route and abandoned river channels such as the successive positions of the Bull River on the western flank of the Rocky Mountains provide evidence of these changing patterns of drainage.

Climate — The climate of the region covered by the excursion varies considerably and reflects the basic landform of the Cordillera. Rapid changes of climate result from the interplay between the prevailing movement of air off the Pacific Ocean and the topography. The windward western side of each mountain range is relatively wet and the leeward relatively dry. Precipitation on the western side of the Coast Mountains averages more than 50 inches (125 cm) annually and this area includes some of the wettest parts of Canada. By contrast, the adjacent southwestern Interior contains some of the driest parts of Canada.

These differences in climate are reflected in marked differences in biotic characteristics which together with topography greatly influence the geological impact of an area. Thus, on most of Vancouver Island, the Cascade and Coast Mountains, and in parts of the Columbia Mountains the rocks are shrouded in deep forest and a tangle of underbrush whereas in much of the Interior between Princeton and Grand Forks they are exposed in arid grasslands and park-like forests. Similar dry forest conditions prevail in the Rocky Mountain Trench, and eastward in the Rockies the forest cover is light. East of the Rockies where the climate is dominated by continental influences, the route from Calgary to Pincher Creek passes through the westernmost parts of the Prairie grasslands.

Summary of Geology — The Canadian Cordillera comprises five structural and lithological belts that largely correspond to the physiographic subdivisions. As noted above, a remarkable feature of the Canadian part of the North American Cordillera is the two belts of crystalline rock separated and flanked by unmetamorphosed or sub-greenschist grade stratified rocks. The Omineca Crystalline Belt in the east consists mainly of metamorphic rocks, whereas the Coast Plutonic Complex in the west is mainly granitic rocks. According to Wheeler (1970b, p. 160) deformation is concentrated in these belts; bulk strain in the eastern belt indicates movement up and towards the northeast whereas that of the western belt reflects movement towards the Pacific.

The depositional, plutonic, and structural records in each belt in the southern Canadian Cordillera are summarized in

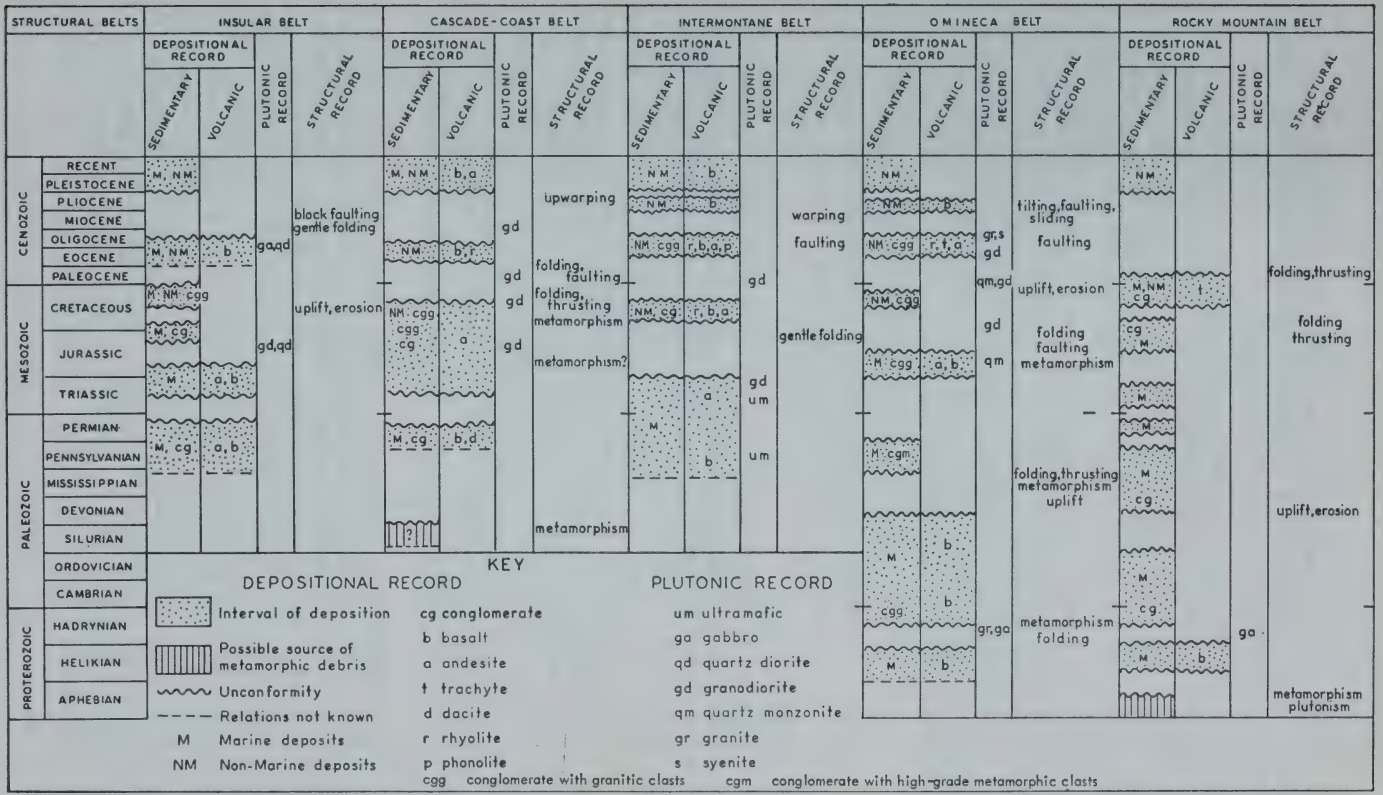
Fig. 1:5. Note that plutonic and volcanic rocks are abundant or common in the western four belts but are almost entirely absent in the Rockies. Also, rocks as old as early Proterozoic occur in the Rocky Mountain and Omineca Belts but the only pre-Devonian rocks known in the western three belts are metamorphic rocks of minor extent occuring in the Cascade Mountains and possibly on southern Vancouver Island.

Fig. 1:5 also summarizes those features encompassed by the term "orogeny" in the southern Canadian Cordillera. Uplift over most of the Cordillera is shown by the general transition from marine to non-marine strata with marked unconformities separating stratigraphic units, in latest Early Cretaceous to Early Tertiary time. Similarly, the bulk of the granitic rocks was emplaced in Jurassic and Cretaceous time and widespread granitic detritus appears in the Phanerozoic stratigraphic record for the first time in the Jurassic. Deformation, as interpreted from the stratigraphic record, is concentrated in the Jurassic, Cretaceous and Early Tertiary periods. Fragmentary records of earlier events are recorded by Devonian-Mississippian folding, thrusting and low grade metamorphism in the Omineca Belt, pre-Devonian metamorphism in the Cascade Mountains and Proterozoic metamorphism, folding and emplacement of granitic rocks in the southern Omineca Belt. However, the present pattern of the Canadian Cordillera largely results from "orogeny" in the Mesozoic and Early Tertiary.

An extensive review of the geology of Western Canada is given by Douglas *et al.* (1970).

Mineral Deposits — Deposits of lead and zinc are characteristic of the mainly sedimentary upper Proterozoic and lower Paleozoic terrain of the Rocky, Purcell and Selkirk Mountains, whereas deposits of copper, molybdenum and iron are typical of the upper Paleozoic and Mesozoic terrain with its abundant volcanic rocks to the west. This change is exemplified by the mines that will be visited during the excursion and by others *en route* which will not be seen. The lead-zinc province is represented by the Sullivan Mine at Kimberley and by the smaller Reeves MacDonald Mine. The copper province is represented by the mines of the Boundary Camp near Greenwood, by Copper Mountain and Ingerbelle Mines near Princeton, by Britannia Mine north of Vancouver and by Western Mines at Buttle Lake. In addition, numerous contact meta-

Fig. 1:5. Summary of the depositional, plutonic and structural records of the Southern Canadian Cordillera.


STRUCTURAL BELTS
INSULAR BELT
CASCADE-COAST BELT
INTERMONTANE BELT
OMINECA BELT
ROCKY MOUNTAIN BELT
DEPOSITIONAL RECORD
SEDIMENTARY
VOLCANIC
PLUTONIC RECORD
STRUCTURAL RECORD
CENOZOIC
MESOZOIC
PALEOZOIC
PROTEROZOIC
RECENT
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS
JURASSIC
TRIASSIC
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
HADRYNIAN
HELIKIAN
APHEBIAN
block faulting
gentle folding
uplift, erosion
upwarping
folding, faulting
folding, thrusting
metamorphism
metamorphism?
warping
faulting
gentle folding
tilting, faulting, sliding
faulting
uplift, erosion
folding faulting metamorphism
folding, thrusting metamorphism uplift
metamorphism folding
folding, thrusting
folding thrusting
uplift, erosion
metamorphism plutonism
KEY
DEPOSITIONAL RECORD
Interval of deposition
Possible source of metamorphic debris
Unconformity
Relations not known
M Marine deposits
NM Non-Marine deposits
cg conglomerate
b basalt
a andesite
t trachyte
d dacite
r rhyolite
p phonolite
cgg conglomerate with granitic clasts
cgm conglomerate with high-grade metamorphic clasts
PLUTONIC RECORD
um ultramafic
ga gabbro
qd quartz diorite
gd granodiorite
qm quartz monzonite
gr granite
s syenite

morphic iron deposits are found in Upper Triassic volcanic rocks with intercalated limestone in the Coast and Insular Mountains along the Pacific margin.

By contrast, gold deposits are found in rocks of all ages. Thus the mines of the Sheep Creek Camp east of Salmo are in Lower Cambrian rocks, the Nickel Plate gold mine at Hedley is in Upper Triassic rocks, and the Dusty Mac prospect at Okanagan Falls is in Eocene rocks of the White Lake basin.

Petroleum and natural gas come from mainly mid-Paleozoic rocks in the Rocky Mountains. Coal deposits are confined to younger rocks, such as the Lower Cretaceous Fernie basin in the Rockies, the Middle Eocene Princeton and Merritt basins in the Interior Belt, and the Cretaceous Nanaimo and Comox basins of Vancouver Island.

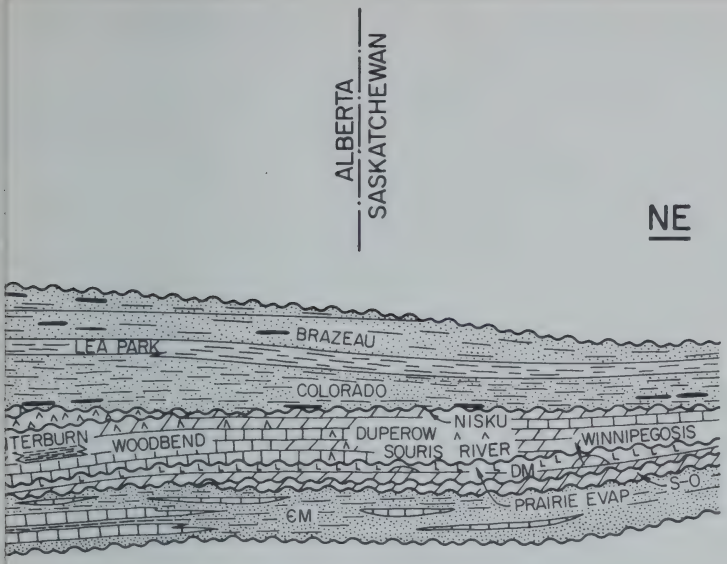
Rocky Mountains and Foothills

by P. L. Gordy, Shell Canada Limited

General Geology

Calgary, the starting point for the excursion, is near the boundary of two major geological regions of Western Canada, the Interior Platform to the east and the Cordilleran Orogen to the west. The Interior Platform extends from eastern Manitoba to western Alberta, underlain by relatively undisturbed Phanerozoic sedimentary rocks resting on a basement of Precambrian crystalline rocks that are the downdip westward extension of the Canadian Shield. The Southern Canadian Rocky Mountains form the eastern part of the Cordilleran Orogen and are characterized by low-angle, west-dipping thrust faults that disrupt both Paleozoic carbonate and Mesozoic clastic sequences but not the underlying crystalline basement.

The Canadian Rockies are subdivided into four physiographic and structural subprovinces from east to west: the Foothills; Front Ranges; Main Ranges; and Western Ranges; and are bounded on the west by the Rocky Mountain Trench (Fig. 2:1). The Foothills consist of deformed Mesozoic clastic rocks and a few relatively large and flat thrusts involving buried Paleozoic carbonates. The Front Ranges are formed by a few major thrust sheets, stacked in imbricate fashion and exposing resistant upper Paleozoic carbonates and Precambrian (Purcell) sediments. The Main Ranges consist of lower Paleozoic and Proterozoic rocks thrust eastward over the adjoining Front Ranges. Structures within the eastern



SHIELD TYPE BASEMENT

CHEMATIC DIAGRAM SHOWING LITHOLOGY AND
'RATIGRAPHY FROM THE INTERIOR PLATFORM
TO THE ROCKY MOUNTAIN TRENCH

FIGURE 2:1

LEGEND

- SHALE
- SHALE, SILTSTONE, SANDSTONE.
- MAINLY MARINE SANDS
- SANDSTONE, CONGLOMERATE.
- EVAPORITE
- ANHYDRITE, GYPSUM.
- LIMESTONE
- LIMESTONE WITH CHERT
- DOLOMITE
- COAL

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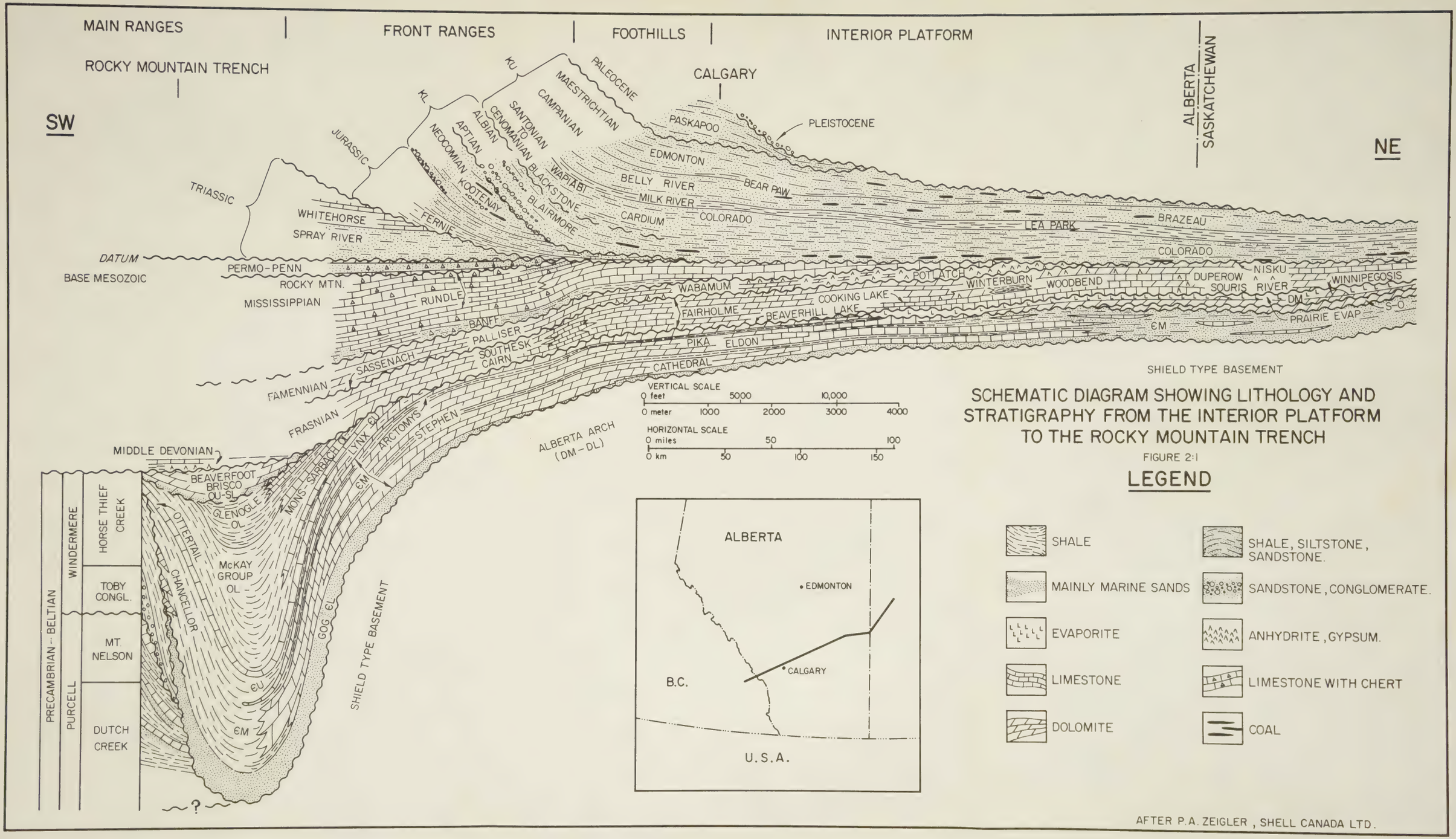

SCHEMATIC DIAGRAM SHOWING LITHOLOGY AND STRATIGRAPHY FROM THE INTERIOR PLATFORM TO THE ROCKY MOUNTAIN TRENCH

FIGURE 2:1

LEGEND

- SHALE
- SHALE, SILTSTONE, SANDSTONE.
- MAINLY MARINE SANDS
- SANDSTONE, CONGLOMERATE.
- EVAPORITE
- ANHYDRITE, GYPSUM.
- LIMESTONE
- LIMESTONE WITH CHERT
- DOLOMITE
- COAL

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part of the Main Ranges are simple broad folds with little thrust faulting. The Western Ranges are characterized by tightly folded lower Paleozoic rocks, in part pelitic stratigraphic equivalents of carbonate units in the Main Ranges. Rocks in the Western Ranges are generally cleaved and the axial planes of folds commonly dip eastward, in contrast with the westward dip of axial surfaces in the other subprovinces. The lithology and stratigraphy of units extending from the Interior Platform across the Rocky Mountain Trench are summarized in Fig. 2:1.

The initial part of the excursion (Days 1, 2 and part of 3) provides an opportunity to examine a complete cross section from the Foothills to the Rocky Mountain Trench. The route crosses the Foothills, Front Ranges and southern part of the Main Ranges, but does not provide a view of the Western Ranges.

Day 1

The route starts at the junction of Highways 2 and 22, immediately south of the Calgary city limits. From mile 0 (Km 0) to about mile 10.5 (Km 16.8), the route crosses the western edge of the Interior Platform. Bedrock consists of Tertiary continental clastics that dip regionally westward. Thrust-faulting is not evident in this zone and seismic data show that the crystalline Precambrian basement dips regionally to the west at approximately 200 feet per mile (38 m/km). Overlying the basement are Cambrian, Upper Devonian and Mississippian carbonates between 4,000 and 5,000 feet (1220 m to 1525 m) thick, above which are Mesozoic and Cenozoic clastic rocks of marine and continental origin.

At mile 10.9 (Km 17.4) the route turns south and crosses the eastern edge of the Foothills belt. Surface folds and faults strike approximately S 20°E. From mile 10.9 (Km 17.4) to about mile 19 (Km 30.4), the low ridge to the east is underlain by east-dipping Tertiary continental sandstones (Paskapoo Formation), and the wooded hills to the west by Upper Cretaceous sandstones (Belly River Formation), also dipping eastward. The prominent grey cliffs in the high range to the west consist of Upper Devonian (Palliser Formation) and Mississippian (Rundle Group) carbonates lying above the McConnell Thrust, and form the first of the Front Ranges at this latitude. The McConnell Thrust can be traced more or less continuously for some 250 miles (400 km) to the north.

From about mile 23 (Km 36.8) to mile 41 (Km 65.6), the route traverses the axis and west flank of the Turner Valley

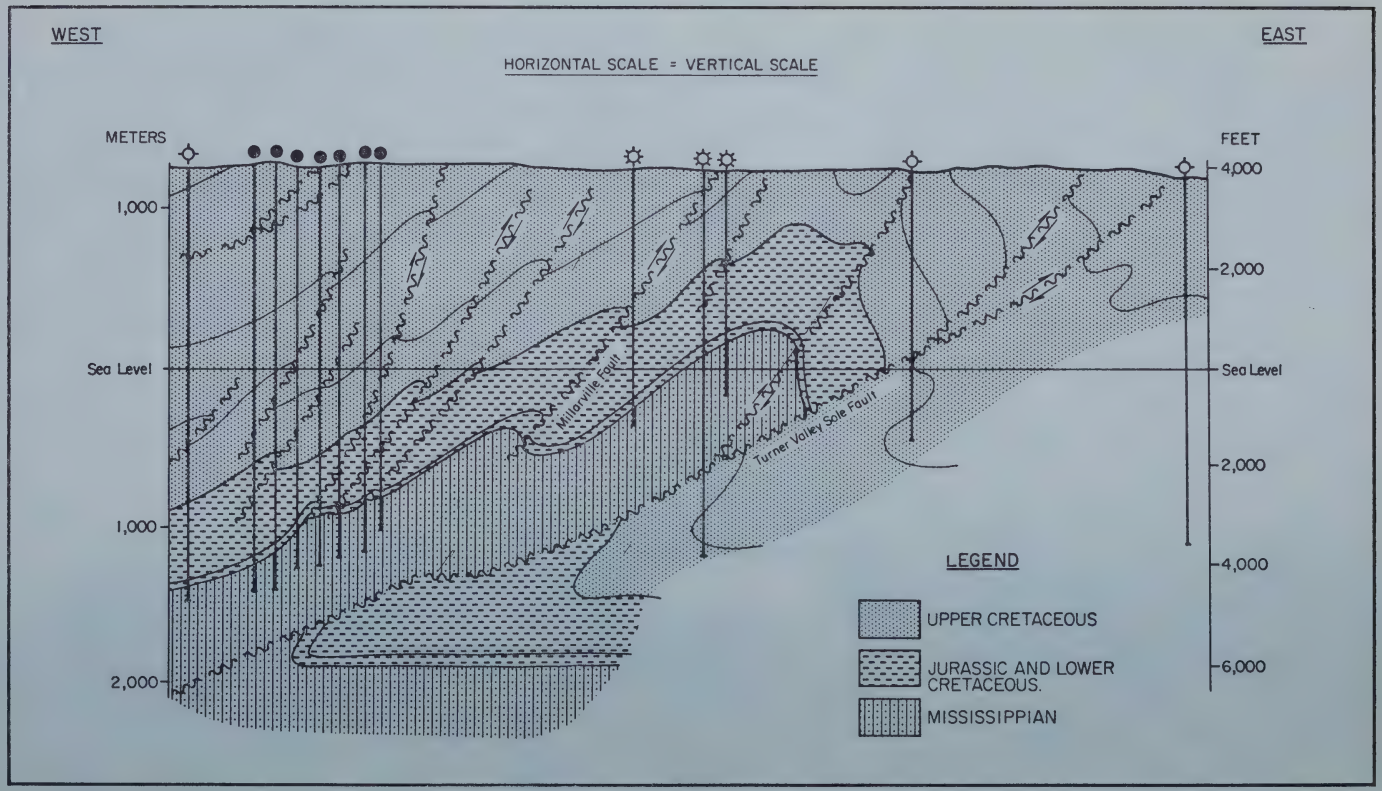


Fig. 2:2. Section through Turner Valley Field.

anticline. This structure is a well-defined surface anticlinal fold containing Mississippian strata in its core and underlain by a major sole fault (Fig. 2:2). The thrust-faulted Mississippian carbonates provide reservoir and trap for Alberta's first major oil discovery, the only commercial oil field found to date in the Foothills Belt; all other Foothills fields contain gas. Oil and gas were discovered at Turner Valley in 1914 in Lower Cretaceous sands and in 1924 gas and condensate in large volumes were encountered in the Mississippian carbonates. From 1924 to 1936 wells were clustered along the crest of the structure and the gas-cap was exploited without regard to conservation practices. However, in 1936, the Turner Valley Royalite No. 1 well discovered oil on the west flank of the structure, and from this time onward the field was developed in an orderly manner. The original amount of hydrocarbons in place is estimated to have been about 1,050,-000,000 barrels of oil, and 1,738 billion cubic feet of gas, with primary recovery of oil estimated to be about 124,000,000 barrels. Over 120,000,000 barrels of crude have been produced to date.

Stop 1:1 (Mile 32.2, Km 51.5) Turner Valley Structure

Stop 1 is on the west flank of the Turner Valley structure and provides a good view from southwest to northwest of typical Foothills terrain underlain by imbricate Mesozoic strata in the foreground, and Paleozoic carbonates overlying major thrust faults in the distance. These thrust faults are the McConnell Fault to the west (Figure 2:3b), and the structurally lower Livingstone Fault to the southwest that forms Plateau Mountain, below which is the Savannah Creek gas field (Figure 2:3c). There is a good view of the Turner Valley structure to the northeast and to the southeast are the Porcupine Hills which are underlain by unfaulted, east-dipping Paleocene sandstones.

From the south end of Turner Valley (about mile 42, Km 67.2), the route continues southwards along the easternmost edge of the Foothills Belt to Highway No. 3. To the west are folded and faulted Cretaceous clastics and Mississippian carbonates forming the Livingstone Range. A major thrust, the Highwood Fault, which does not expose Paleozoics, lies immediately west of the excursion route to approximately mile 70 (Km 112) (See Figure 2:3c). The route also follows along the western base of the Porcupine Hills. The Porcupine Hills are underlain by gently to moderately east-dipping unfaulted Paleocene strata.

Stop 1:2 (Mile 94, Km 150.4) Oldman River, Upper Cretaceous strata

This stop, along the banks of the Oldman River, provides a closeup view of Upper Cretaceous strata and their structural attitudes in this area. The exposed rocks are sandstones and shales of the St. Mary River Formation, the upper major part of which contains strata of fresh water origin. This formation is transitional to underlying marine shales of the Bearpaw Formation.

Figure 2:4 shows the structural setting at this locality.

Stop 1:3 (Mile 99.8, Km 159.7) View of Lewis and Livingstone Thrusts.

To the south the position of the Lewis Thrust is visible. The peaks consist of Proterozoic sediments which are thrust over Upper Cretaceous rocks. (see cross-section, Figure 2:3e and Figure A). The Waterton gas field, the largest in the Foothills belt, underlies the leading edge of the Lewis Thrust. Note the change in strike (from northerly to westerly) in the surface trace of the Lewis Thrust. The northward continuation of the Lewis Thrust lies below the high peaks visible in the distant northwest.

The Livingstone Range, visible to the west, exposes faulted and anticlinally folded Mississippian strata at the leading edge of the Livingstone Thrust. This range is an excellent model of gas-producing structures in the subsurface. Note the southward plunge of the Range.

At the junction of Highway No. 3, the route turns west and crosses folded and faulted Upper Cretaceous strata of the outer part of the Foothills. Three major thrusts, the Livingstone, Coleman and Lewis Faults, are crossed between Mile 117.3 (Km 187.7) and the Continental Divide.

Figure 2:3d illustrates the structure along this segment of the route.

Stop 1:4 (Mile 127.4, Km 203.8) Frank Slide

This stop is in the centre of the Frank Slide, which occurred on April 29, 1903. The slide destroyed a portion of the town of Frank with the loss of seventy lives. The peak at the head of the slide is Turtle Mountain, composed of anticlinally folded Mississippian (Rundle Group) carbonates, thrust onto the Lower Cretaceous coal-bearing Kootenay Formation.

The cause of the slide is attributed to two main factors: 1) frost wedging in the highly fractured carbonates and 2) the

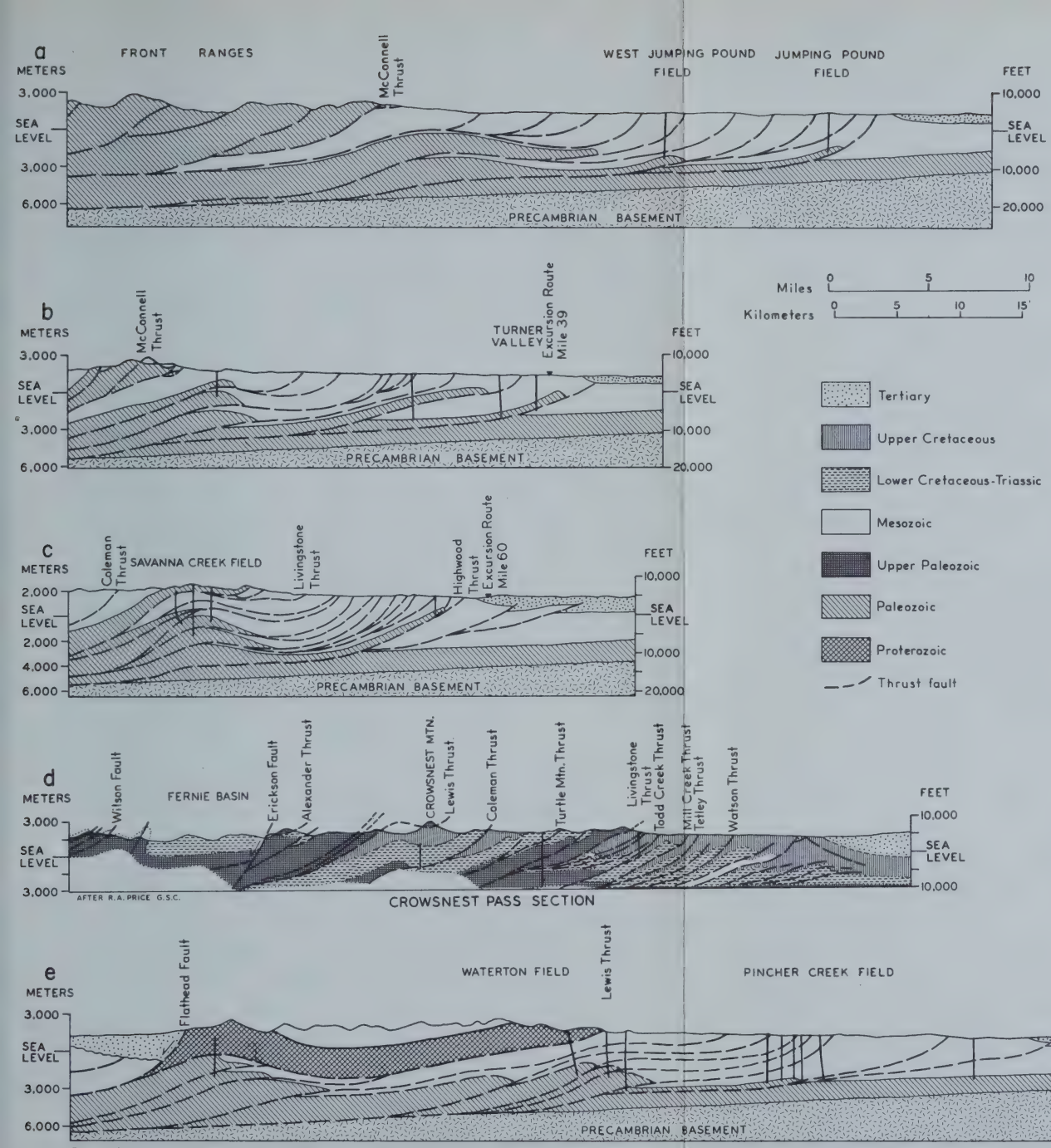


Figure 2-3. Serial cross-sections of the eastern Rocky Mountains, Foothills, and western Interior Plains from the latitude of Calgary in the north (a) to near the International Boundary (e). From Bally et al, 1966 and Price. Location of cross-sections shown on Figure A.

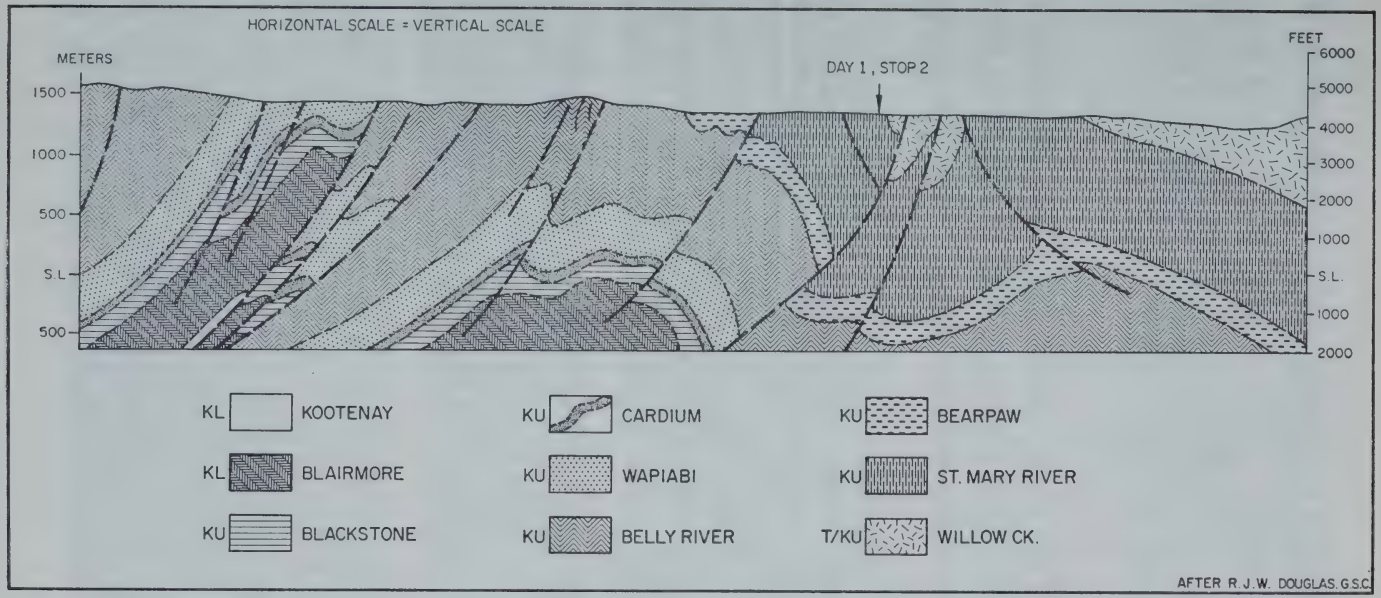


Fig. 2:4. Structure of Mesozoic rocks at Oldman River.

possible effect of coal mining operations which extended under the base of the mountain.

The termination of Day 1 is at the towns of Frank and Blairmore. These communities, like others in the Crowsnest Pass (Bellevue to Fernie), depend primarily on coal mining operations which exploit the coal resources of the Kootenay Formation (Lower Cretaceous).

Day 2

The excursion route continues westward along Highway No. 3, crossing the Lewis Thrust and Continental Divide (at the first of the Front Ranges at this latitude) and enters the Province of British Columbia at mile 143.0 (Km 229).

The structure along this portion of the route is shown by Figure 2:3d.

Stop 2:1 (Mile 135.6, Km 217) Crowsnest volcanics

The Lower Cretaceous Crowsnest Formation is an alkaline volcanic unit composed of trachyte and phonolite detritus which is restricted to the Crowsnest Pass region of the Southern Foothills Belt. It is the only Phanerozoic volcanic unit in the Eastern System at this latitude. It attains its maximum thickness, 1600 feet (490 m), near this locality but thins markedly to the north, south and east. It is 500 feet (150 m) thick on the Livingstone thrust plate, and absent farther to the east.

The Crowsnest volcanics may be related to leucocratic alkalic igneous rocks that intrude Paleozoic carbonates of the Lewis thrust plate at Crowsnest Pass, and which are more abundant in the Flathead region of southeastern British Columbia. Although the evidence is not conclusive, the intrusives are apparently allochthonous and are of Early Cretaceous age.

Stop 2:2 (Mile 140.4, Km 224.6) Upper Paleozoic section

From this stop there is a good view of the Devonian and Mississippian section above the Lewis Thrust. The lower cliff-forming unit is the Palliser Formation (Famennian), consisting mainly of dark grey, finely crystalline limestone. The overlying Mississippian contains shale and interbeds of cherty limestone and chert at its base. The upper portion and bulk of the formation consists of variably bedded limestones and dolomites. The Mississippian section visible on the ridge to the northwest is fault-thickened to about 4500 feet (1375 m) from its normal thickness of about 3300 feet (1005 m).

Stop 2:3 (Mile 154.5, Km 247.2) Kaiser Coal Operation
by J. J. Crabb, Crowsnest Industries Ltd.

The coal fields of southeastern British Columbia extend more than 100 miles (160 km) northward from the International Boundary. The coal-bearing Kootenay Formation (Upper Jurassic and/or Lower Cretaceous age) underlies an estimated 400 square miles (1024 sq. km) and is believed to contain 57 billion tons of coal. Only a fraction of this is considered to be recoverable by today's methods and economics.

Kaiser Resources' surface and underground mines are near the northern end of the Fernie Coal Basin, the largest of the various fields. In the Michel area the coal measures are about 2000 feet (610 m) thick and contain 11 seams 3 feet (1m) or more thick. Since 1899 underground mines have operated eight of these seams.

The large open-pit mines first developed by Kaiser in late 1969 in the stratigraphically lowest No. 10 (Balmer) seam, account for most of their production. The seam averages more than 40 feet (12 m) thick in an explored area 8 miles (13 km) long (north-south) and 3 miles (4.8 km) wide. Pits are located along the east side of Baldy Mountain where conditions approach a dip-slope. (see Fig. 2:5).

In 1971 sales contracts were valued in excess of one billion dollars. The capital outlay by this time for the new plant, equipment, and related facilities was about 130 million dollars.

Approximately 8 million short tons of raw coal must be produced which, in one year, requires removing 50 million cubic yards of rock material from above No. 10 seam. This is mainly accomplished by large shovel (25 cubic yard) — truck (200 ton) combinations working along strike benches. Overburden is drilled, blasted, loaded and hauled to dump areas in the valleys east of the pit limits.

Underground mines in No. 10 seam were previously developed in Sparwood Ridge and in the west flank of Baldy Mountain, where cover exceeds present overburden-to-coal ratios for open-pit mining.

Stop 2:4 (Mile 174.5, Km 280.9) Structures surrounding Fernie

City of Fernie. The Lizard Range seen to the southwest and west, consists of an overturned panel of Jurassic to Devonian strata underlain by the Lizard Thrust. Triassic and Permian rock form the base of the range and Devonian rock caps the highest peaks. The Trinity Mountains (Three Sisters) to the north are formed by recumbently folded

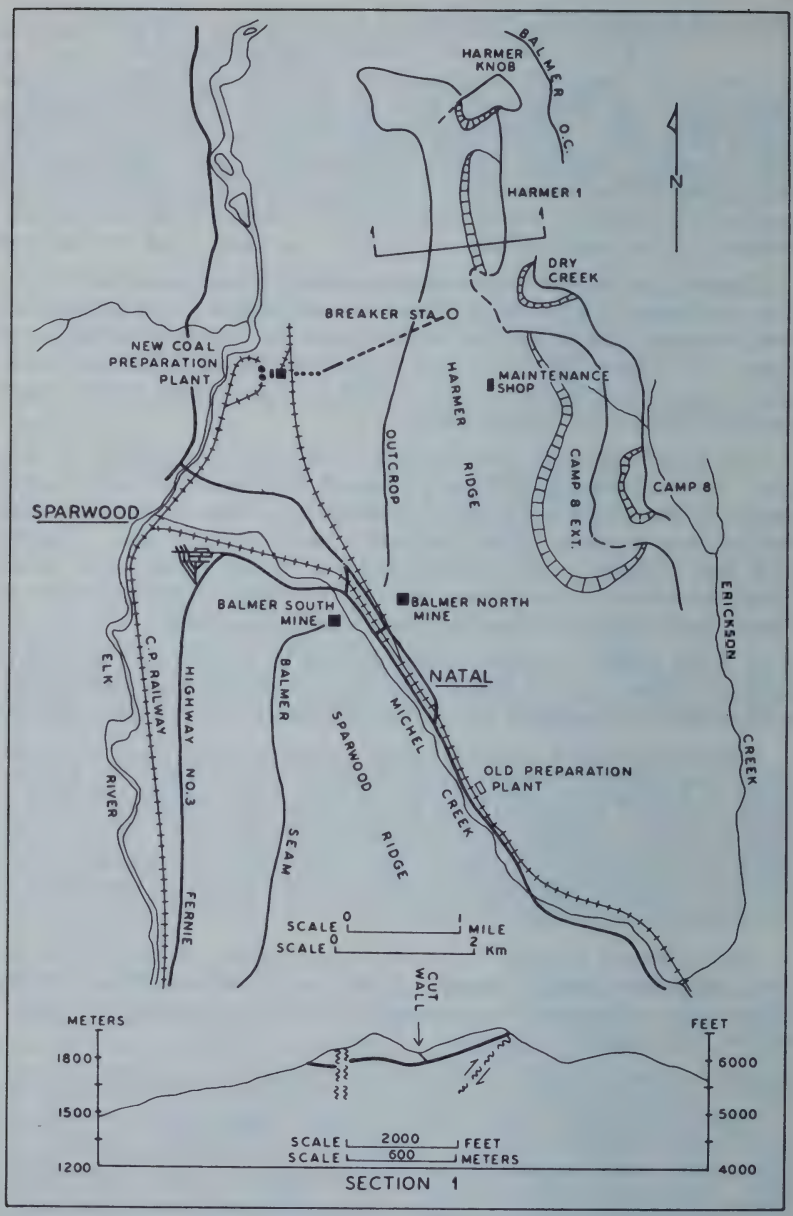


Fig 2:5. Sketch map of coal mining operations in Fernie Coal basin.

Devonian-Mississippian beds (Hosmer Nappe). The lower slopes are underlain by overturned Mississippian and younger rocks and the peaks by right-side-up Mississippian. The near vertical beds visible on the south face of Mount Hosmer (looking east of north) are Devonian and Mississippian and form a klippe of the Lizard Thrust.

The high ridge to the east is capped by resistant conglomerates and sandstones of Late Jurassic and Early Cretaceous age and forms the western rim of the Fernie Basin. The Elk River valley is eroded primarily in Jurassic shales of the Fernie Group.

Western Rocky Mountains and Southern Rocky Mountain Trench

by G. B. Leech, Geological Survey of Canada

General Geology

The western edge of the Rockies at this latitude consists of Proterozoic, Paleozoic and Mesozoic strata repeated in a succession of folded thrust plates that are truncated on the west by normal faults in the Rocky Mountain Trench.

The Rocky Mountain Trench is a chain of valleys of varied physiographic and structural character that extends from near latitude 47°N to beyond 59°N, a distance of about 1000 miles (1600 km). It defines the western boundary of the Canadian Rocky Mountains. The southern part, south of latitude 50°N, consists of linked tectonic valleys initiated by block faulting in half-graben style and modified by substantial infilling, by glaciation and by post-glacial effects (Leech 1966). This part of the Trench is characteristically asymmetrical, with an abrupt east wall and a contrastingly less steep and more irregular west flank. Its axial part is devoid of outcrops except at a few localities.

The segment of the Trench seen on this excursion traverses an allochthonous terrain that was thrust across its present site in Cretaceous to (?) Paleocene time. The ensuing block-faulting broke through these thrust plates at least early enough to influence the deposition of Late Miocene sediments. Little is known about the Tertiary sediments in the Trench; the Miocene strata, the only ones yet dated, are unlikely to be the oldest as they do not occupy the lowest depressions. By analogy with the structurally comparable Flathead Valley, 25 miles (40 km) to the east, the Trench faulting probably

began at least as early as Eocene time and continued into Oligocene time.

No major strike-slip movement has occurred in the locus of the Rocky Mountain Trench south of latitude 50°N. The allochthonous terrain was thrust across it before the Trench itself originated. This is indicated by a combination of the following criteria: the occurrence of comparable pairs of contrasting stratigraphic sequences on opposite sides of the Trench (Stop 5), the presence in this area alone of the same Devonian and Mississippian formations on both sides of the Trench, and by the distribution of an unique Precambrian lava (Purcell lava) on both sides of the Trench (Leech, 1966). Mile 0 for the day is at the Elk River bridge (West Fernie).

Day 3

The Lizard Range to the southwest of the Elk River bridge (West Fernie) consists of steeply dipping overturned Devonian to Jurassic formations in a fold limb that stands, truncated, upon a thrust fault over Jurassic strata. The bare rocks at the top are Upper Devonian (Palliser Formation) and Mississippian; the wooded slopes are in Pennsylvanian-Permian and Mesozoic strata, and the fault is near the base of the mountain. The route goes southward for 10 miles (16 km) along the base of the range below the fault, in poorly exposed Jurassic strata (Fernie Group), then passes through Triassic into upper Paleozoic strata. The east side of the valley is in Jurassic and Lower Cretaceous rocks that include the coal-bearing Kootenay Formation. At mile 11.6 (km 18.6) are outcrops of Pennsylvanian (Rocky Mountain Formation) sandstone structurally beneath the Lizard Thrust. These beds are on the east limb of a large north-plunging anticline (Broadwood anticline). The Elk River begins to turn west here and for the next 4.7 miles (7.5 km) it cuts through this anticline, down through the Mississippian carbonates (Rundle Group, Banff Formation) to Devonian limestone (Palliser Formation). The lowest outcrops on the roadside are Mississipian.

Stop 3:1 (Mile 16.2, Km 25.9) Wigwam thrust

This stop is on the trace of the Wigwam Thrust that, at this level, brings Proterozoic (Upper Purcell), Cambrian and Devonian beds onto Mississippian strata forming the west flank of the Broadwood anticline. Both thrust plates are below the Lizard plate.

The stratigraphic sections in the Wigwam plate and in the underlying Broadwood anticline are the same. The sub-Cambrian and sub-Devonian unconformities are major regional ones, though there is little structural discordance beneath the Cambrian, and the Upper Devonian lies disconformably on the Cambrian. The Proterozoic (Upper Purcell) strata are unmetamorphosed shallow-water deposits (argillites, siltstones, sandstones, dolomites) with ripple marks, mud cracks, intraformational breccias and stromatolites, examples of which will be seen at Stop 4 on the west side of the Rocky Mountain Trench.

In the view northward, which includes the more complete section of the Wigwam thrust plate, the exposed fault trace and the profile of the Mississippian slope downhill from it illustrate almost exactly the true dip of the fault plane.

The Wigwam Fault is younger than the Lizard Fault. The Wigwam Fault cut upwards through the competent upper Paleozoic footwall strata until it reached the incompetent Triassic beds in the immediate footwall of the Lizard Fault and proceeded along them and into this earlier plane. The more westerly part of the Lizard Fault was thus carried bodily upward and forward on the Wigwam thrust plate and its deformation was further accentuated by folding generated by movement over the step-shaped Wigwam fault plane. Finally, the whole Wigwam-Lizard system was folded over the Broadwood anticline. Thus the overturned position of the Paleozoic strata beside the first 10 miles (16 km) of today's excursion is the cumulative effect of a series of rotations that began with the folding prior to their truncation by the Lizard Fault and continued through the folding of that fault.

Stop 3:2 (Mile 20.0, Km 32.0) Rocky Mountain Trench

Here the route has entered the Rocky Mountain Trench. The east wall along the Galton Range, visible in profile southward from here, is a fault-line scarp of Proterozoic rocks with, at the 49th Parallel at least, Devonian and Mississippian strata at its foot.

This stop is on the edge of a gravel terrace built during the waning stages of Pleistocene glaciation. The Trench had earlier been almost full of ice; at Stop 3:4, for example, the ice was at least 4500 feet (1400 m) thick. A lobe of ice still occupied the floor of the Trench after its flanks were ice-free. Rivers debouching from the mountains met this ice, were deflected by it and flowed southward, constrained between it and the wall of the Trench. As the ice receded

northward the rivers abandoned successive segments of their marginal channels and spilled across to the lowest part of the Trench floor. Although the edges of the Trench are scoured and terraced by vigorous river action, there are lower, more central parts of it that contain excellent examples of drumlinoid, fluted and other sub-ice patterns.

The Elk River was deflected more than 19 miles (30 km) southward, to below the 49th Parallel. It never did regain its preglacial channel directly into the Trench, but became entrapped in one of its deflection gorges, and it still flows along the margin of the Trench for nearly 6 miles (10 km) before breaking out across the floor. Its original direct channel is buried somewhere beneath this stop. The gravel terraces here are the work of ice-marginal waters that flowed southward across the mouth of the Elk Valley and then, slightly later, spilled out westward down the "dry cascade" in the channel below this stop.

From this locality continue past Galloway (Mile 27.7, Km 44.3) where the folded Wigwam thrust plate plunges northward beneath the folded Lizard Thrust on the east side of the Trench. The fault is in the tributary valley (Sand Creek), which has Devonian and Mississippian strata on its south side and the over-riding Proterozic (Lower Purcell) on its north side.

Here the route leaves Highway 3 and proceeds northward on an Industrial Road for 3.9 miles (6.5 km) to Stop 3.

Stop 3:3: Proterozoic rocks and east wall of Trench

Here the east wall of the Trench, and a fringe of its floor, consists of characteristically rusty weathering quartzites and argillites of the Proterozoic (lower Purcell) Aldridge Formation. Beneath it, under the Lizard Thrust, are upper Paleozoic strata of the Wigwam plate. Above it, to the east, the Proterozoic sequence is overlain by the Devonian and younger strata in the Lizard Range that were viewed at the beginning of today's excursion.

This thrust plate is cut off at the Trench by a west-dipping fault (Murray Lake Fault) that abuts Devonian and Mississippian against the Proterozoic. The Devonian and Mississippian formations extend, broken by faults, across the floor of the Trench and up onto its west flank, where they rest unconformably on Proterozoic strata.

The trace of the Murray Lake Fault is distinct where it crosses a spur ridge in the mid-distant view northward from

this stop. It dips west at about 40° at this level. Stratigraphic and structural evidence indicate that it is a normal fault, i.e., that the Devonian and Mississippian in the Trench are down-dropped continuations of the Devonian and Mississippian that overlie the Proterozoic of the east wall and are not an upthrust segment of a plate that the Proterozoic overrides.

Return to Highway 2 at Galloway. At Mile 31.0 (Km 49.6), the view eastward to Sand Creek shows the upper Paleozoic rocks plunging beneath the Proterozoic at the Lizard Fault.

The route goes across and then almost along strike of a series of drumlinoid and fluted sub-ice structures. The till in one of them is exposed along the west side of the road near Mile 36 (Km 57.5). Upper Devonian reefoid carbonates are exposed near Mile 38 (Km 61).

The excursion leaves Highway 3 and proceeds to the lunch stop at the Fish Hatchery at Bull River, about 3 miles (4.8 km) to the north. The Bull River, now in its preglacial valley, was at one stage deflected by ice to a course through Galloway and southward beyond Stop 2.

Return to Highway 3, cross Kootenay River, pass Mississippian outcrops and at Mile 47.4 (Km 75.8) turn left off Highway 3 and proceed 1.6 miles (2.5 km) on secondary and private roads to a farmyard below Stop 4.

Stop 3:4 Basal Devonian and underlying upper Purcell strata

This stop is at the base of the Devonian-Mississippian succession whose occurrence on the floor of the Trench makes this segment of it distinctive. Here it rests unconformably on Proterozoic strata in the west flank of the Trench, whereas at Stop 3 it is faulted against the Proterozoic of the east wall.

The Devonian rests on upper Purcell (Gateway) strata just above the Purcell lava, which is a regional marker in the the Proterozoic succession. The Gateway Formation (sandstones, argillites and dolomites) contains features such as ripple marks, scour patterns, stromatolites and oolites. There are a few salt casts which elsewhere are abundant and characteristic of higher parts of the Gateway Formation.

The basal Devonian contains a distinctive breccia-conglomerate that is a totally unsorted jumble of blocky and slabby fragments of Proterozoic rocks. This is succeeded by pebble conglomerate and coarse sandstone, partly dolomitic, containing fragments of armoured fish. The Devonian was deposit-

ed with small angular discordance on an irregular surface near the northern margin of a region that had stood relatively high since Precambrian time.

Return to Highway 3.

Stop 3:5 (Mile 52.2, Km. 83.5) Bedrock relief of the east side of the Rocky Mountain Trench and comparative stratigraphy of its flanks.

The Steeples segment of the east wall of the Trench exhibits an almost true-thickness section of the two Proterozoic formations that overlie the Aldridge Formation of Stop 3. Though the Steeples rise 5,000 feet (1,500 m) above the floor of the Trench they expose only half of its bedrock relief. Three deep bedrock depressions are hidden beneath the gravel floor of the part of the Trench between 49°10′N (just south of Stop 2) and 49°40′N (just north of here). One of them is about 5,000 feet (1,500 m) deep, i.e., the bedrock floor of the Trench there is about 2,450 feet (750 m) below sea-level. Two of these deep basins are separated by the zone of Devonian and Mississippian outcrops that crosses the Trench between Stops 3 and 4. The variations in depth along the axis of the Trench are interpreted as being due to variations in the amount of vertical movement undergone by different sub-blocks during the block faulting that initiated this part of the Trench.

The east side of the Trench here contains two contrastingly different stratigraphic sections brought together by the Dibble Fault, a pre-Trench folded thrust almost perpendicular to the east wall. South of the fault, in its footwall, Devonian strata rest directly on Proterozoic strata (just below the level of the Purcell lava) whereas north of the fault a thick sequence of Cambrian, Ordovician and Silurian strata intervenes. (The part of the northern section visible from this stop is all Proterozoic). The west side of the Trench here likewise contains two contrasting stratigraphic sections, brought together on the Moyie Fault, a pre-Trench folded thrust fault that strikes into it. South of the Moyie Fault, in its footwall, Devonian strata again rest on nearly the same level of Proterozoic strata (Stop 4) whereas north of the fault the Proterozoic is succeeded by a thick sequence of Lower Cambrian, and probably younger Cambrian strata, cut off by the present erosion surface. The presence of these comparable pairs of contrasting stratigraphic sections on both sides of the Trench is part of the evidence for absence of major strike-slip movement.

From this locality continue to Kimberley, on Highway 3 and 95A, crossing the St. Mary River.

Purcell Mountains

by H. C. Morris, Cominco Ltd.

General Geology

On Day 4 the excursion crosses the Purcell Mountains from the Rocky Mountain Trench to the Purcell Trench. In this part of the range elevations reach 9850 feet (3000 m) although the highway does not climb above 3300 feet (1000 m). For most of the day the excursion will follow the Moyie River which provides a pass through the Purcell Mountains.

The whole day is spent in rocks of the Proterozoic Purcell Group, which is equivalent to the Belt Supergroup in the U.S.A. The succession in this region may be regarded as a basin-filling sequence, commencing with deep water turbidites and laminated argillites, passing upwards through sandstones and mudstones deposited at shallower depths and terminating in a sequence of argillaceous, silty and calcareous rocks which include stromatolitic and reefal units. The lowermost, deep-water beds are the Aldridge Formation. These are followed by the Creston Formation that includes the transition beds and those deposited at moderate depth. The shallower members are included in the Kitchener and Siyeh Formations. In the area traversed no distinction is made between the Kitchener and Siyeh units and they are referred to as the Kitchener-Siyeh, or more commonly, Kitchener Formation.

In late Proterozoic time the Purcell Group was uplifted and folded into a north-plunging anticlinorium, characterized by broad open folds of essentially concentric style. Accompanying or preceeding this event, extensive sheets of gabbro and quartz gabbro were intruded, particularly into the lowermost formations. These are referred to as the Moyie "Diorite" intrusives, and are probably equivalent to the basaltic flows that overlie the Kitchener Formation in eastern exposures of the Purcell Group.

Orogenic or epeirogenic events occurred in later geological time but their effects are difficult to date precisely. Prominent northeast-striking faults traverse the area but cut only lower Proterozoic formations. These faults are characterized by an apparent large stratigraphic upthrow on the north side that gives the appearance of thrust faulting. However, a substantial strike-slip component is probable as well. By repeated upthrow on the north sides of these faults, the outcrop area of the Purcell Group is extended to the north for about 44 miles (70 km).

Day 4

Stop 4:1 Sullivan Mine, Number 1 Shaft area

This stop is on a dump of Aldridge Formation argillite and greywacke that has been excavated from the Sullivan lead-zinc mine. The Number 1 Shaft intersects the southeast fringe of the sulphide lens at a depth of approximately 1650 feet (500 m). The view eastward is across the Rocky Mountain Trench which is about 19 miles (30 km) wide here, where it changes direction markedly. To the north the Trench strikes northerly for roughly 25 miles (40 km), its east wall being formed by rocks of the Purcell Group which have been strongly folded on axes that plunge generally northwards, whereas its west wall is formed by less deformed rocks of the upper Purcell and Windermere Groups. To the south the Trench strikes southeasterly for approximately 31 miles (50 km) to Elko where it again assumes a more northerly strike.

From Stop 1 the excursion route leads southwest through Kimberley (Mile 0 at city center) to Marysville and Wycliffe. About 2 miles (3.2 Km) east from Marysville is the northeast-trending St. Marys Fault that brings Cambrian strata on the south against the lower Proterozoic Aldridge Formation on the north. The terraced land near Wycliffe is composed essentially of Tertiary sands and lacustrine muds that have been dissected by the St. Mary River. A quartz monzonite stock of Cretaceous age outcrops 2.5 miles (4 km) east of Wycliffe.

On reaching Cranbrook (Mile 20.2, km 32.5) the excursion route turns southwest and into the Purcell Mountains. For the first 6 miles (10 km) the area is underlain entirely by rocks of the lower Proterozoic Aldridge Formation.

Stop 4:2 (Mile 28.5, Km 45.8) Lumberton Junction, Aldridge Formation

Flat-lying greywackes, siltstones and argillites of the lower Proterozoic Aldridge Formation are exposed in low cliffs along the highway. The beds display considerable variation in thickness and grain-size, but almost all are graded and may be described as modifications of the general turbidite model of Bouma (1962). Sedimentation features include grading, lamination, convolute bedding, flame structures and cross-lamination. Indistinct grooves and flutes may also be noted on the under surfaces of certain beds. The units are regarded as part of the Aldridge flysch, believed to be the product of

extensive turbidite deposition in a deep water basin (Bishop, Morris & Edmunds, 1970).

Six hundred feet (185 m) up the slope to the east, the Aldridge Formation is intruded by one of the Moyie gabbro sills. The path up the slope passes more examples of turbidite varieties within the Aldridge Formation and reveals surprisingly little contact metamorphism until within 35 feet (10 m) of the contact of the sill. The quartz-gabbro sill is a medium-grained even-textured rock containing approximately 50 percent hornblende and 40-45 percent plagioclase. This sill has been traced for a distance in excess of 60 miles (100 km).

To the west, capture of the upper Moyie River by the headwaters of the south-flowing lower Moyie River may be seen. The flat swampy ground in the immediate foreground is underlain by alluvial gravels which were the site of early gold mining. The hills in the middle distance up to 6 miles (10 km) away are formed by rocks of the Aldridge Formation which is at least 16,400 feet (5000 m) thick in this area.

From Lumberton the excursion route follows the Moyie River southeast to the north end of Moyie Lake where the road crosses another major northeast-trending fault, the Moyie Fault, which lies under low ground near Peavine Creek. A stratigraphic downthrow to the south of more than 13,000 feet (4000 m) brings rocks of the Kitchener Formation in contact with rocks of the middle Aldridge Formation.

Stop 4:3 (Mile 34.5, Km 55.5) Moyie Lake, Kitchener Formation

Grey, white and buff-coloured mudstones, calcareous mudstones and limestones of the Kitchener Formation are well exposed in the road cut at this point. A striking feature is the abundance of minute calcite-filled planar and convolute fractures. In certain units, an abundance of convolute calcite-filled fractures leads to a fabric called "molar tooth" structure. There is considerable debate about the origin of these features with suggestions ranging from structural to biogenic origins. Ripple-marked surfaces are common as are other shallow-water indicators. In this region, the Kitchener Formation is at least 6500 feet (2000 m) thick.

The southwest extension of the Moyie Fault follows the valley of Lamb Creek on the west side of Moyie Lake whereas the lake itself lies along the axis of the Moyie anticline, a major structure within the Purcell anticlinorium.

Stop 4:4 (Mile 35.8, Km 57.5) Moyie Lake, Creston Formation

Green, purple and white sandstones, sandy shales and shales of the Creston Formation occur in road cuts and also are very well displayed in large boulders obtained during road construction. These sandstones are regarded as the products of deposition in relatively shallow water, probably in a shelf environment. Ripple-marks and crossbedding are abundant, together with fracture-filled patterns which have been interpreted as both mudcracks and subaqueous desiccation features. The Creston Formation is 6500 feet (2000 m) thick and consists of alternating siltstone, quartzite and argillite that grade down into deep water argillite at the top of the Aldridge Formation. The upper contact with the Kitchener Formation is also gradational and is normally placed at the first occurence of significant carbonate in the sequence.

From this stop the excursion continues southwards along the axis of the Moyie anticline. Owing to the northerly plunge, the road passes downward through the stratigraphic sequence into Aldridge Formation near the town of Moyie. At this locality, lead and zinc were mined in the early part of the 20th century at the St. Eugene Mine. After passing the south end of Moyie Lake, the highway follows the strike of the west limb of the Moyie anticline as far as the village of Yahk, remaining in Aldridge Formation rocks the whole distance. At Yahk the excursion route turns westward and within 3 miles (5 km) crosses the west limb of the anticline, passing upwards into the Creston Formation. At Goatfell the excursion route again crosses the Moyie Fault, this time to the downthrown side, and for the remainder of the journey to Creston the road traverses rocks of the Aldridge Formation.

At Creston the excursion route reaches the Purcell Trench, a prominent northerly-trending structural feature which is over 250 miles (400 km) in length. This is probably the locus of considerable faulting, and although displacement is not apparent in this area, 60 miles (100 km) to the south near the town of Sandpoint, Idaho, there is evidence of a graben-type structure. The Purcell Trench marks a fundamental change in the character of the rock on the route of the excursion. The east side of the trench south of Creston is formed by prominent cliffs of Aldridge Formation (the Ramparts). These display typical Aldridge lithology and demonstrate the thickness and uniform nature of this turbidite sequence. To the west are highly deformed metamorphic rocks.

Selkirk and Monashee Mountains

by J. T. Fyles, B. C. Department of Mines and Petroleum Resources

General Geology

Outcrops along the excursion route during the next two days illustrate some aspects of the geology of the Kootenay Arc. The Kootenay Arc is a curving belt of complexly deformed rocks at least 250 miles (400 km) long that trends northeast for 100 miles (160 km) across Washington into British Columbia, north to northern Kootenay Lake and northwest to near Revelstoke. The Arc lies between the Purcell anticlinorium on the east and the Shuswap Metamorphic complex on the west and contains a thick succession of sedimentary and volcanic rocks that range in age from earliest Cambrian to Mesozoic. Structurally it is a zone of polyphase folds and steeply dipping strata in various grades of regional metamorphism. Obscure, folded thrust faults of regional extent within the Arc probably extend beyond it both to the east and the west, but the Arc itself is not bounded by thrust faults. Strata on the western side of the Purcell anticlinorium steepen in dip and pass westward into isoclinally folded rocks of the Arc. These rocks grade westward into the Shuswap complex by a relatively rapid increase in metamorphic grade.

The Shuswap complex consists of schist and gneiss mainly in the amphibolite facies of regional metamorphism. These rocks are derived from strata ranging in age from Precambrian (Proterozoic strata and possibly crystalline basement) to late Paleozoic or younger. In general aspect the complex contains broad gneiss domes with gently dipping foliation and a wide variety of superimposed folds. Most rocks of the complex have a prominent east-trending penetrative lineation that contrasts with the curving north-trending lineations of the Kootenay Arc.

Irregular large and small masses of granitic rock, mainly quartz monzonite and granodiorite, occur throughout this region. The largest is the Nelson batholith, the northern part of which yields a potassium-argon age of 164 m.y. Small Tertiary intrusions of syenite and monzonite are common in the southern part of the Kootenay Arc and continue for many miles to the west.

Figure 5:1 is a schematic diagram showing relationships between various lithological units in Selkirk and Monashee Mountains. Three phases of folding are recognized at many

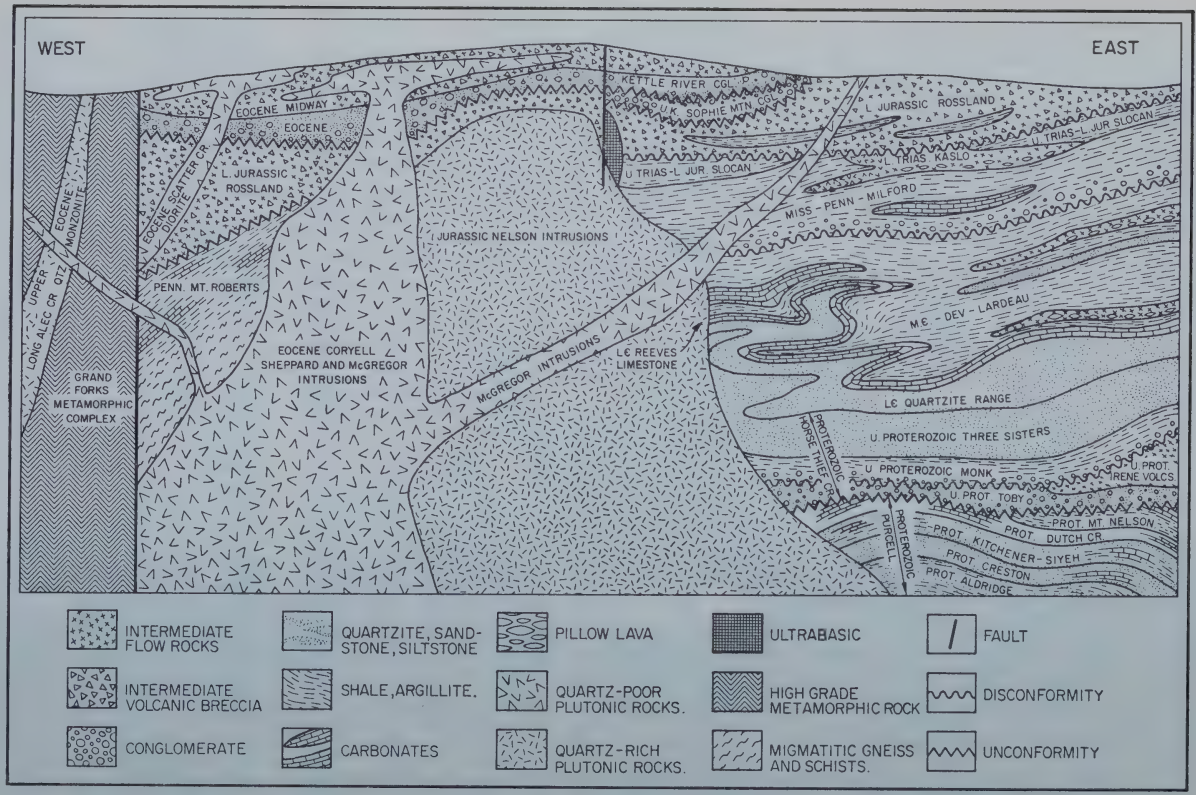


Fig. 5:1. Relationships of Formations in the Columbia Mountains (Creston to Grand Forks segment).

places within the Arc. The oldest, or phase 1 folds, are isoclinal with gently plunging axes and curved axial planes. Phase 2 folds are more open and are commonly cleavage folds with steeply dipping axial planes and axes parallel with the Phase 1 folds. Phase 3 folds at many localities are minor structures with a steep plunge. Research and speculation are continuing on the correlation of the phases of folding and their distribution in time.

The Arc contains important deposits of silver, lead, zinc, and tungsten. Large low-grade stratiform lead-zinc deposits are present in Lower Cambrian carbonates near Salmo. In the Slocan area, there are rich silver-bearing veins and shear zones in Triassic argillite near the northern edge of the Nelson batholith. Silver-lead-zinc veins and massive replacements of calcareous rocks along fractures occur near central Kootenay Lake.

Day 5 Purcell Trench at Creston

The excursion route from Creston crosses the Creston Flats that contain rich agricultural land reclaimed from flooding by a system of dykes. The flats are along the Kootenay River which flows northward along a meandering course into the south end of Kootenay Lake, and annual flooding has produced a series of natural levees along the river bank that now are partly replaced by dykes.

Kootenay Lake is in part of the Purcell Trench, a topographic lineament extending from 100 miles (160 km) south of the International Boundary to almost 200 miles (320 km) north of it. The Trench in the United States follows a zone of faulting which probably runs through Creston and northward into the Purcell Mountains east of Kootenay Lake. Kootenay Lake is in a fiord-like valley deepened by glacial action that probably originated along belts of easily eroded phyllite, schist, and slate between resistant formations such as quartzite and granitic rock. Creston is less than 100 miles (160 km) north of the southern limit of Wisconsin ice. Fluvio-glacial material, deposited as the ice retreated, fills the valley south of Kootenay Lake.

On the western side of the valley west-dipping members of the Purcell Group on the western limb of the Purcell anticlinorium can be seen in the distance to the southwest outlined by bands of trees on the hillside.

On the west side of the Creston Flats the road turns north and west entering the valley of Summit Creek. Figure 5:2 is a

diagrammatic cross-section along Summit Creek and Stagleap Creek to the west showing the first four stops of Day 5. Mile 0 for the day is the junction of Highway 3 and 3A, in Creston.

Stop 5:1 (Mile 9, Km 14.5) Deformed and metamorphosed Purcell strata, Summit Creek

Outcrops of mica schist and micaceous quartzite along lower Summit Creek are deformed and metamorphosed equivalents of the Purcell Group seen yesterday. The extent of the metamorphic zone is not known. The southern edge of a large granitic mass lies two miles north of the road. The styles of folding seen in the outcrops are like those found in the Kootenay Arc to the west.

The rocks are muscovite-biotite schist with irregular lenses of quartz-feldspar pegmatite. Minor folds in the schists have three styles:—

1. Isoclinal folds, plunging northeast at 20 to 40 degrees with curved, generally steeply-dipping axial planes.

2. Open similar folds essentially co-axial with the isoclinal folds, with axial planes dipping at moderate angles to the east and southeast.

3. South-plunging wrinkles and kink folds.

These may be interpreted as folds belonging to three phases in a time sequence in which the open folds (2) deformed and tightened the earlier isoclinal folds (1) and both (1) and (2) were deformed by (3).

Stop 5:2 (Mile 20, Km 32) Toby Conglomerate, Summit Creek

The Purcell Group is overlain unconformably by the Toby Conglomerate which outcrops mainly as a single layer on the western limb and northern crest of the Purcell anticlinorium for more than 150 miles (240 km). Because Summit Creek crosses the conglomerate obliquely, it is exposed along the highway for several miles. Beds at Stop 2 strike 040 degrees, are essentially vertical, are cut by a steeply dipping cleavage, and have a fine penetrative lineation plunging 35 degrees to the northeast. Although the internal structure of the formation is not known, it is probably tightly folded. Cobbles as much as a foot across consist mainly of white quartzite, grey micaceous quartzite, and white quartz in a phyllitic micaceous matrix. Elsewhere along the road a common rock of the Toby Formation is a dark grey phyllite with scattered cobbles of buff to white dolomite. In a recent study (*see* Aalto, 1971) the Toby Conglomerate is described as a diamictite and thought to be of glacial origin.

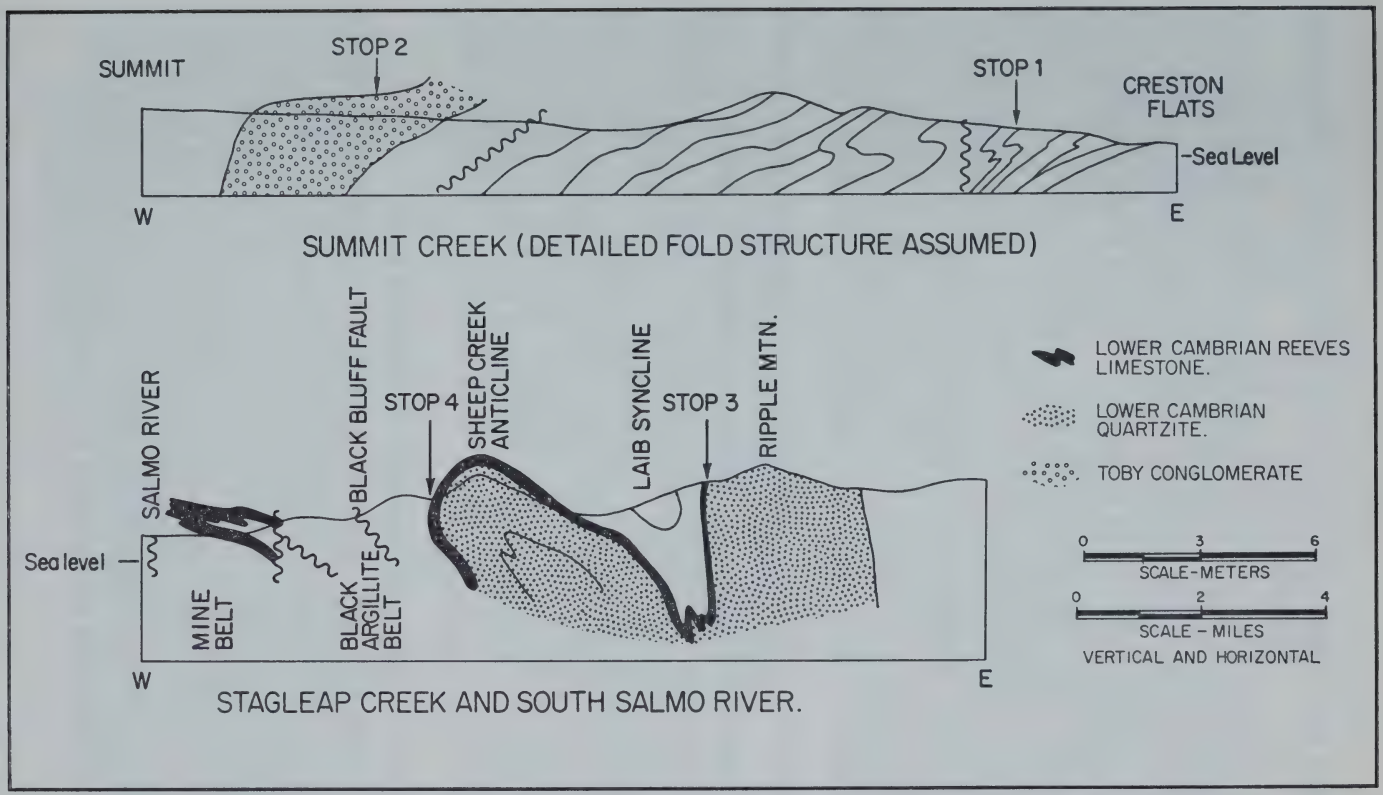


Fig. 5:2. Diagrammatic cross-section along Summit and Stagleap Creeks.

Stop 5:3 (Mile 32, Km 51.2) Lower Cambrian formations, Stagleap Creek

Between Stops 2 and 3 the excursion route passes through volcanic rock and quartzite stratigraphically above the Toby Conglomerate. These rocks dip steeply and details of the structure are not well known. Near the pass between Summit and Stagleap Creeks they contain an irregular stocklike mass of granitic rock. This sequence of bedded rocks includes the Precambrian-Cambrian boundary, although here it is not marked by any significant stratigraphic break. The first known Lower Cambrian rock is exposed at Stop 3 and the same stratigraphic interval is repeated again at Stops 4 (Sheep Creek anticline) and 6 (Reeves MacDonald Mine). The local stratigraphy at these three places is summarized in the following diagram (Figure 5:3). This group of formations can be recognized for at least 150 miles (240 km) to the north with only minor facies changes and has been a valuable marker in deciphering the structure of the Kootenay Arc.

Stop 5:4 (Mile 39.8, Km 63.7) Sheep Creek anticline, south Salmo River

Between Stops 3 and 4 the road obliquely crosses an isoclinal upright syncline complicated by a series of northerly trending steep faults and then swings westward through a broad anticline known as the Sheep Creek anticline. The youngest rocks exposed within the syncline are Ordovician slate and argillite and the whole Cambrian section well down into the Lower Cambrian Quartzite Range Formation is repeated on the Sheep Creek anticline. Stop 4 is on the western limb of the anticline and the fold itself is clearly visible along the road and on the slopes to the south for approximately a mile east of the stop.

Stop 5:5 (Mile 48.8, Km 78.1) Black Bluff fault

A short distance west of Stop 4 the route crosses the Black Bluff Fault which separates the Sheep Creek anticline from a group of probable Ordovician black slates and argillites constituting the Black Argillite Belt. These rocks, which are complexly folded and faulted, have an overall synclinal form bounded on the east and west by regional strike faults. These faults are probably old thrusts that have been folded and faulted. Stop 5 is at an exposure of the Black Bluff Fault in which tightly folded argillites and slates of the Black Argillite Belt lie west of the fault and Middle Cambrian argillaceous limestone, dolomite and phyllite lie to the east.

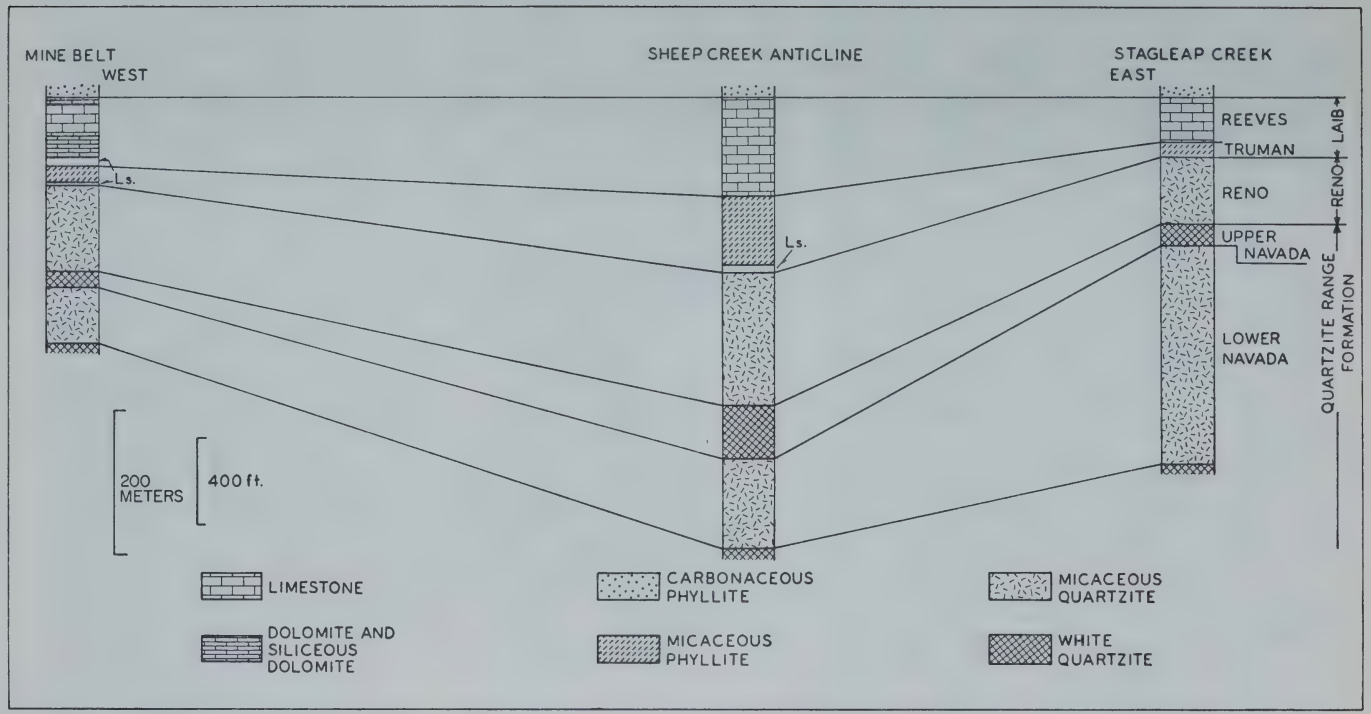


Fig. 5:3. Lower Cambrian sections, southern part of the Salmo area.

Stop 5:6 (Mile 56, Km 89.6) Glory hole, Reeves MacDonald Mine

The Reeves orebody exposed in the uppermost workings of the Reeves MacDonald Mine is one of several stratiform lead-zinc deposits in the Lower Cambrian limestone of the Kootenay Arc. In the Salmo area these deposits are in a structural belt, called the Mine Belt, which lies west of the Black Argillite Belt and is separated from it by a complex fault. The Reeves orebody is a replacement of dolomitized parts of the Reeves limestone by pyrite, sphalerite and galena. It has the form of an attenuated syncline with limbs striking eastward and dipping 50° to 70° south and axis plunging 50 degrees towards S50°W (Figure 5:4). It is broken into segments by northerly-trending normal faults which dip to the east. When all the faulted segments are considered, the orebody has a plunge length of more than 5000 feet (1500 m) from which about 6.5 million tons of ore were mined with an average grade of silver 0.1 oz. per ton, lead 1%, zinc 3.4%, cadmium 0.02%.

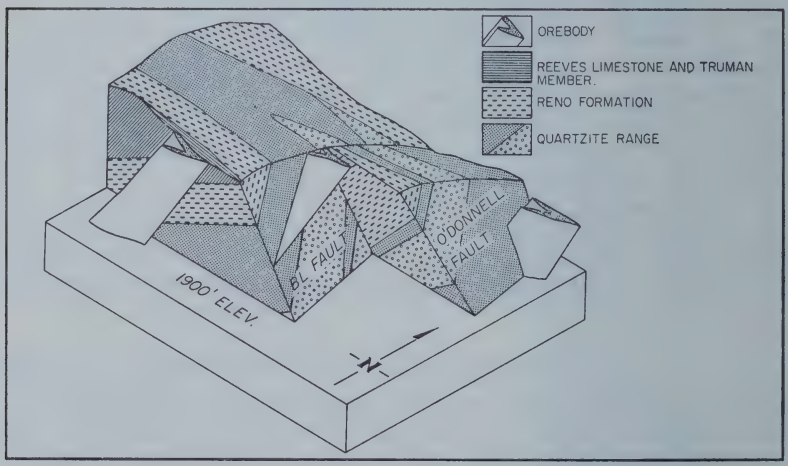


Fig. 5:4. Isometric sketch of the Reeves orebody and its faulted segments.

From the mine the route returns to the junction of the Creston highway and continues northward to Nelson. South of Salmo the rocks on the east side of the valley belong to the lower Paleozoic sequence which contains the Reeves limestone and associated lead-zinc deposits. North of Salmo on both sides of the highway are Mesozoic volcanic rocks and

granitic rocks of the Nelson Plutonic suite. A Tertiary alkalic stock is exposed on the highway just south of Ymir.

Day 6

The route on Day 6 crosses the southern part of the Nelson batholith and follows its western, northern and eastern margins. The western contact along Slocan Lake is a fault which separates the batholith from schist and gneiss of the Shuswap Metamorphic complex. The northern and eastern margin is an irregular intrusive contact against highly deformed argillite, slate, and limestone of the Triassic Slocan Group. A zone of thermal metamorphism and marginal deformation up to 2 miles (3 km) wide follows this contact. The wall rocks are part of the Kootenay Arc and display multiple folding characteristic of Arc structure.

The Nelson batholith typically is composed of porphyritic, medium-grained granitic rocks with phenocrysts of potash feldspar commonly up to 2 inches (5 cm) long. The rocks vary from hornblende-biotite quartz diorite to biotite granodiorite and leuco-quartz monzonite. Non-porphyritic phases are well exposed in rock cuts along the highway west of Nelson and porphyritic phases can be seen at places along the road for 25 miles (40 km) east of Nelson.

From the junction of Highways 6 and 3A in Nelson (Mile 0, Km 0) the road runs westward along Kootenay River through marginal phases of the Nelson batholith. At South Slocan (Mile 14, Km 22.5) it turns northward up the Slocan River into rocks of the Shuswap Metamorphic complex, passing through a small gneiss dome before reaching a second dome near Slocan Lake.

Stop 6:1 (Mile 47, Km 75) Hybrid gneiss at Slocan

The cliffs along the eastern side of Slocan Lake for 2 or 3 miles (3 to 5 km) north of Slocan are part of the Valhalla gneiss dome of the Shuswap Metamorphic complex. They are described by Reesor (1965) as hybrid gneiss and constitute one of the principal layers in the dome. They consist of intimately intermixed metasedimentary rocks and leucogranitic gneiss and pegmatite. The hybrid gneiss is underlain by a uniform granitic gneiss which is not exposed on the road and both these units are separated from the Nelson batholith a half mile (0.8 km) to the east by a fault. Three foliations F1, F2 and F3, and three lineations L1, L2, and L3 can be recognized in the hybrid gneiss. F1 is essentially parallel with compositional layering, dips 25 to 30 degrees to the east

and is parallel to the limbs and axial planes of isoclinal folds that plunge ENE at about 15 degrees. F2 is a cleavage trending 150 degrees and dipping 40 degrees southwest that is parallel with axial planes of open folds that plunge 15 degrees to the south. F3 consists of small, closely-spaced, discrete fractures that cut the earlier foliations, strike southerly and dip 45 to 60 degrees to the east. (*see* Ross and Kellerhals 1968, p. 857-859).

Stop 6:2 (Mile 58, Km 93) Slocan Lookout

The view to the north and west shows the gently-dipping layers of schist and gneiss forming the northern flank of the Valhalla gneiss dome.

Rocks at the lookout are highly crushed porphyritic granodiorite in the fault-zone along the western side of the Nelson batholith.

Stop 6:3 (Mile 70, Km 112) Slocan Argillites, Three Forks

North towards New Denver the road passes out of the Nelson batholith into Triassic argillaceous rocks of the Slocan Group and continues eastward in these rocks to within a few miles of Kootenay Lake. The regional structure of the Slocan Group is poorly understood but the local structure is known in detail because it controls the location of rich silver-lead-zinc orebodies. The rocks are complexly folded and transected by at least two northwesterly-trending slate belts. Stop 3 shows thin-bedded, blocky argillites that are lightly metamorphosed and dip steeply to the southwest. They are probably right side up and lie on the lower limb of a huge northwesterly-trending recumbent fold concave to the southwest. The structure of the upper limb of the fold is well known in the mines to the southeast (see Hedley, 1952).

Stop 6:4 (Mile 78, Km 125) Whitewater Slate Belt, Bear and Fish Lakes

At Bear and Fish Lakes the road enters a belt of slate several miles wide and stays within this belt to within 3 miles (4.8 km) of Kootenay Lake. The slate dips to the southwest and lies above a southeasterly-trending layer of competent mafic volcanic rocks that forms a rib of high mountains to the east. Near the lakes, folded argillite grades northeastward into contorted slate. Axial-plane cleavage, transposed beds, and folded slaty cleavage can be seen in many outcrops.

Before reaching Bear Lake the road passes north of the abandoned town of Zincton and the workings of the Lucky

Jim Mine which produced over one million tons of lead-zinc ore between 1893 and 1953 from fracture-controlled replacement deposits in folded and brecciated limestone in the argillite sequence. At 1.5 miles (2.5 km) east of Fish Lake the road goes through the abandoned town of Retallack and passes near the portal of the Whitewater silver lead mine. East of this mine the road cuts obliquely across bedding and cleavage planes in limestone and slate. The regional strike is followed for about 10 miles (16 km) then the route turns eastward through the volcanic rocks and into high-grade regionally metamorphosed Paleozoic rocks exposed on Kootenay Lake near Kaslo.

Stop 6:5 (Mile 108, Km 173) Folds, North end of Kootenay Lake

Salient features of the folds in northern Kootenay Lake are shown in Figure 6:1. Rocks along the road and western shore of the lake north of Kaslo are mica schist, quartzite and marble, derived from lower Paleozoic strata. Prominent cliffs of limestone near Shroeder Creek are equivalent to the lower Cambrian strata seen yesterday at the Reeves MacDonald Mine.

South of Kaslo, mica schist, calcareous schist and limestone with prominent sills of felsite and leucogranite dip at low to moderate angles to the west. These are complexly folded rocks of probable Paleozoic age and lie a few miles east of the Nelson batholith. The dominant westerly dip persists on the east side of the lake and can be seen in distant views. Twenty miles south of Kaslo the road turns westward through these metasediments into the granitic rocks of the batholith which are exposed in road cuts as far as Nelson.

Monashee Mountains and Interior Plateau

by V. A. Preto, B. C. Department of Mines and Petroleum Resources and J. W. H. Monger, Geological Survey of Canada

General Geology

Between Nelson, in the Columbia Mountains, and Princeton, just east of the Cascade Mountains, the geology is dominated by Tertary block-faulting on all scales that bring together blocks of very different geological character. Because of this and because of the abundance of plutonic rocks, there is no continuity to enable ready determination of the regional pre-Tertiary structural pattern, even though the geology of some individual blocks is well-known (e.g. Preto, 1970).

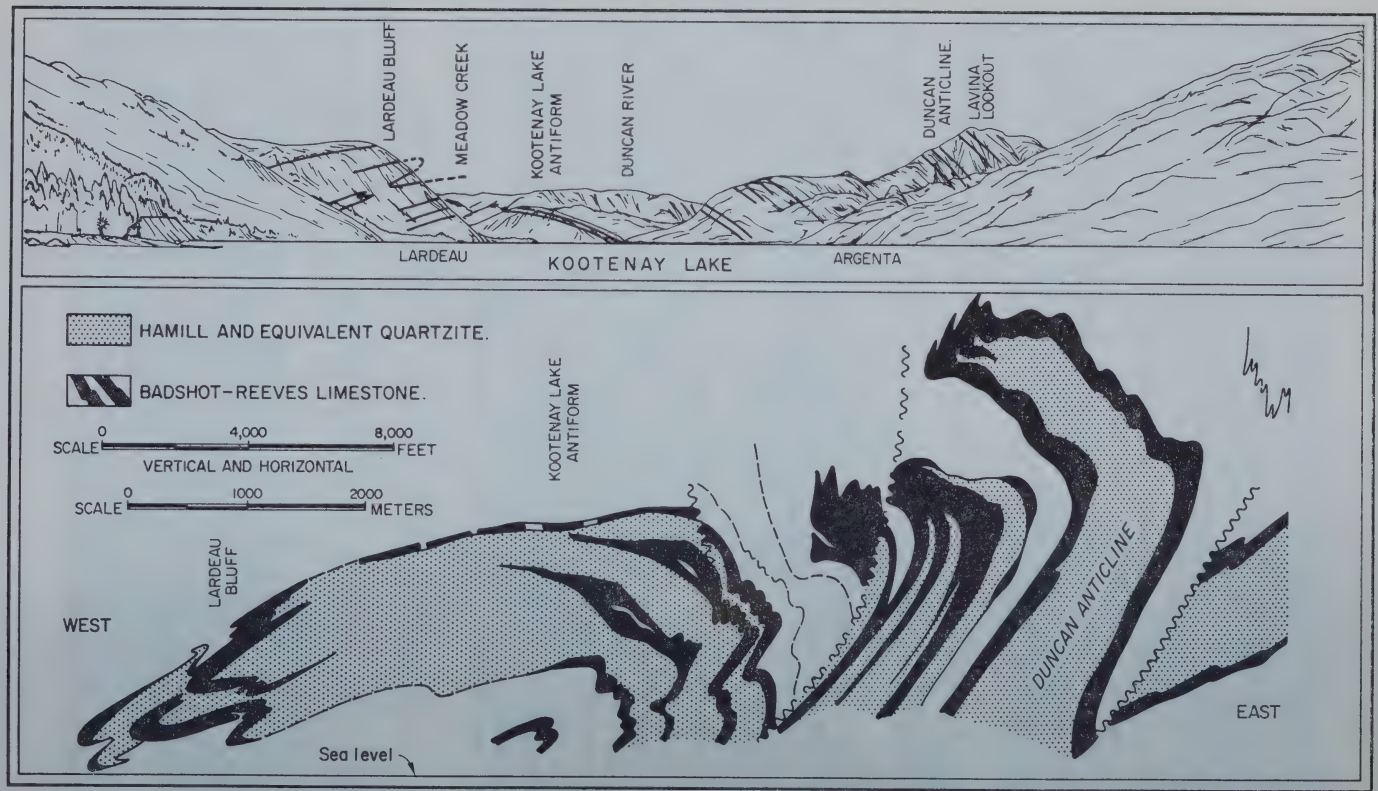


Fig. 6:1. Sketch showing structure at north end of Kootenay Lake.

Five main groups of rocks are found in this region (*see* Fiure 5:1):—

1) High grade metamorphic rock that closely resembles gneiss of the Shuswap complex and forms a possibly continuous infrastructure. This group is well exposed near Grand Forks and is known as far west as the Okanagan Valley.

2) Argillite, chert, mafic volcanic rock and minor limestone and ultramafic rocks of late Paleozoic age that are commonly metamorphosed to greenschist facies.

3) Largely unmetamorphosed Triassic and Jurassic argillite, volcanic rocks and minor limestone, that unconformably overlie the upper Paleozoic rocks. These rocks predominate west of the Okanagan Valley.

4) Jurassic-Cretaceous quartz diorite, granodiorite and quartz monzonite plutons such as the Nelson batholith and a subordinate amount of syenite, granite and monzonite of Tertiary age. Together these are the most common rocks in the region.

5) Lower Tertiary volcanic and sedimentary rocks that lie with marked angular unconformity on all older rocks and are clearly genetically related to the block faulting. They exhibit a wide range in composition from rhyolite, through predominant trachyandesite to phonolite and are probably the extrusive equivalents of some of the Tertiary plutonic rocks.

Day 7 provides a brief review of each of these groups. Mile 0 is at the junction of Highway 6 and 3A, in Nelson.

Day 7

Stop 7:1 (Mile 10.2, Km 16.3) Nelson quartz diorite at Brilliant Dam

From Nelson the road follows the south bank of the West Arm of Kootenay Lake for a short distance, then the north bank of the Kootenay River. The highway rock-cuts are in more or less foliated granitic rock of the Nelson batholith. The rock at Stop 7:1 is foliated and lineated quartz diorite which, on the hill to the southwest, is cut by a large number of light coloured felsite dykes. The hydroelectric power dam at this stop, like others seen along the Kootenay River, is part of a system that belongs to the West Kootenay Power and Light Company.

On the way to Stop 7:2, west of the Columbia River the excursion route follows Blueberry Creek through an area of poor exposure mainly underlain by granitic rocks of the Nelson

batholith which are cut by syenite and monzonite dykes of the Tertiary Coryell intrusions.

Stop 7:2 (Mile 49.2, Km 78.6) Mount Roberts Formation, McRae Creek

Rocks of the Mount Roberts Formation are of Permo-Carboniferous age and are thus among the oldest dated along the International Boundary between Nelson and Princeton. At this stop they are steeply dipping interbedded argillite and calcareous siltstone, locally tightly folded and thermally metamorphosed to biotite and diopside hornfels by the Coryell pluton of Tertiary age, which lies on the south side of McRae Creek valley.

Coryell quartz syenite porphyry dykes cut the Mt. Roberts Formation at this locality. Between here and Stop 7:3 the excursion descends along McRae Creek and then follows the eastern side of Christina Lake for some distance. Most rocks seen in highway cuts in this section are part of the Mt. Roberts Formation.

Stop 7:3 (Mile 61.5, Km 98.5) Paragneiss and schist of the Grand Forks Group, Cascade turn-off

The valley of Christina Lake is followed by the north-trending Kettle River Fault, which marks the eastern boundary of an uplifted block of high-grade metamorphic rocks of the Grand Forks Group. The west boundary of this block, which is roughly 12 miles (19 km) across, is the subparallel Granby Fault, which south of the International Boundary merges with a system of faults that mark the east side of the Republic graben.

The Grand Forks metamorphic rocks are a southern extension of the Shuswap Metamorphic complex and for the most part are altered to sillimanite-almandine-orthoclase sub-facies grade of regional metamorphism. They include a variety of paragneiss, schist, quartzite, marble, calc-silicate gneiss, and much pegmatite, and are cut by large bodies of granodiorite gneiss. These strata are deformed into east-trending folds with south-dipping axial planes and with arched axes that plunge gently to the east and west (*see* Figure 7:1).

At this locality the section consists mostly of calcareous schist, paragneiss and calc-silicate gneiss, with at least two generations of pegmatite. This heterogeneous assemblage is characterized by a variable and highly disharmonious style of deformation which involves much boudinage and folds that range in style from isoclinal to sub-concentric. Folds here

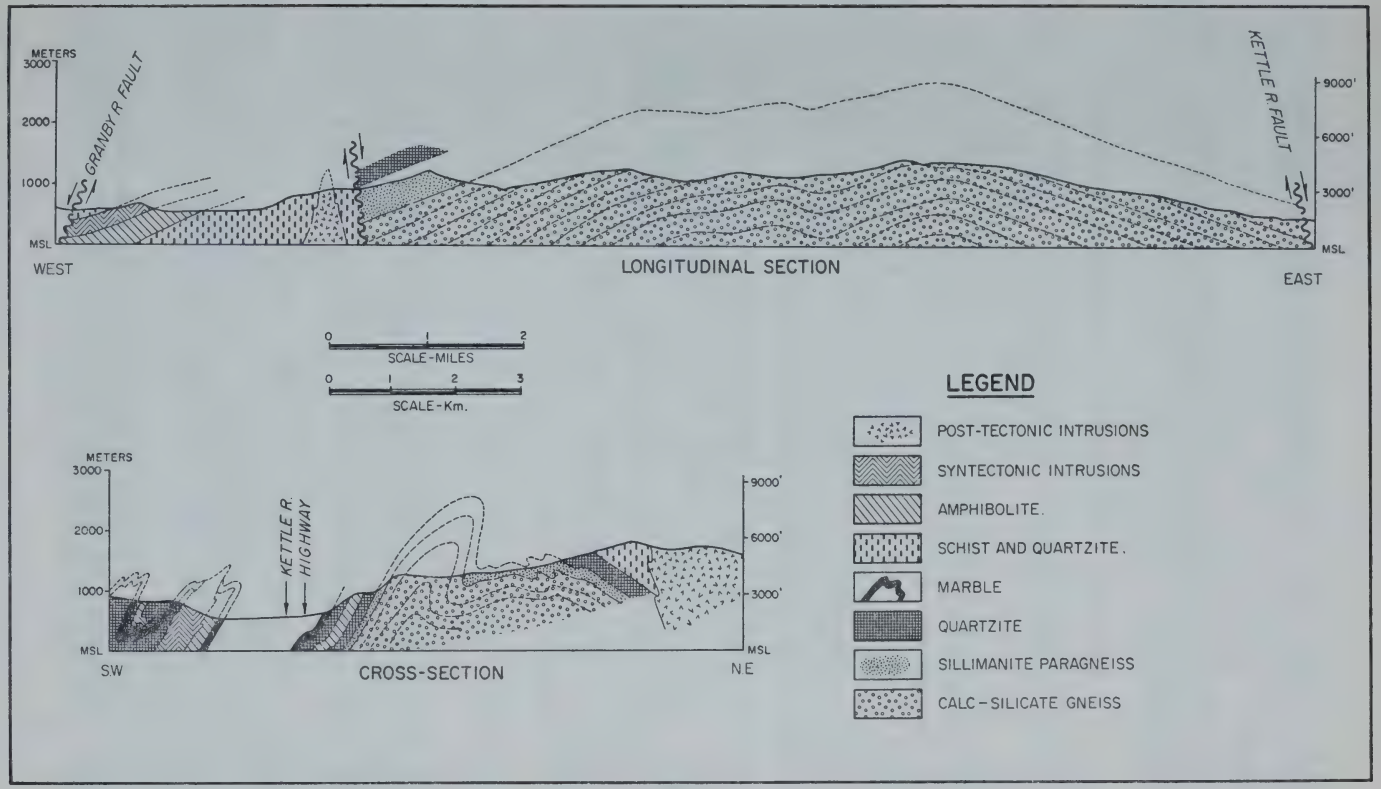


Fig. 7:1. Generalized longitudinal and cross-section of the Grand Forks Group.

plunge gently ESE and have south-dipping axial planes. A post-tectonic granitic dyke is found at the east end of the rock cut.

On the way to Stop 7:4 Grand Forks metamorphic rocks can be seen in cuts along the highway as far west as the town of Grand Forks.

Stop 7:4 (Mile 78.5, Km 125.5) Grand Forks Lookout

This vantage point is a few hundred yards north of the International Boundary, and offers a good view to the east along the Kettle River, and to the north along the Granby River. The town of Grand Forks, surrounded by fertile agricultural land, is situated at the confluence of the two streams. The slag piles and ruins of the Grand Forks smelter, one mile north of town, are all that remain of a plant which early in the century processed most of the direct-smelting copper ores from the mines of the Boundary Camp to the west. The ruins of two other similar smelters will be seen at Greenwood and at Boundary Falls, between Stops 7.5 and 7:6.

The lookout is a short distance to the west of the Granby River Fault, which marks the western boundary of the Grand Forks horst of metamorphic rocks. In the western outcrops these rocks are folded into a westerly-plunging antiform clearly outlined by a sill of syenite that can be seen from here.

The excursion now ascends along July Creek to an area underlain by sedimentary and volcanic rocks ranging in age from Permian to Jurassic.

Stop 7:5 (Mile 86.2, Km 138.0) Upper Triassic limestone-conglomerate

Rocks at Stop 7:5 exemplify the third group in the region, namely unmetamorphosed Mesozoic strata. Boulders and cobbles of limestone, lithologically similar to Middle Triassic *Daonella*-bearing limestone found in the area, are in a maroon matrix containing volcanic detritus. The age of the conglomerate is considered to be Upper Triassic.

About 6 miles (10 km) to the west, Middle Triassic rocks lie in with angular unconformity on the upper Paleozoic rocks (Little and Thorpe, 1965) indicating Permo-Triassic tectonism in the region.

Between Stops 7:5 and 7:6 the excursion traverses mainly upper Paleozoic and Mesozoic strata cut by Mesozoic plutons. This is an important mining region in the Cordillera, where

numerous deposits of copper, gold, silver, lead and zinc have been worked over the last 70 years.

About 4 miles (6.4 km) south of Greenwood the excursion enters a structurally depressed area containing down-faulted Eocene volcanic and sedimentary rocks unconformably overlying upper Paleozoic and Mesozoic strata. The fault bounding the east side of these Tertiary rocks has an indicated displacement of at least 6,000 feet (1800 m).

Stop 7:6 (Mile 118.3, Km 189.1) Faulted Eocene volcanic rocks, Kettle Valley

The Kettle Valley exposes a block-faulted Eocene sequence (Figure 7:2). This sequence consists of basal sandstone and conglomerate of the Kettle River Formation, in part derived from the underlying terrane, and, in part, composed of acid tuff. Above this is the Marron Formation, (Midway Formation of Daly, 1912), with a lower part of alkaline trachyte and phonolite flows, some containing feldspar rhombs, a middle part of andesite and trachyandesite and an upper part of acidic andesite. Many feeders to the various flows bear a marked similarity to the Tertiary plutonic rock to the east. Potassium argon ages of 49 ± 2, 48 ± 2 m.y. from these rocks indicate their Middle Eocene age (Mathews, 1963). The succession bears a remarkable resemblance to the lower two-thirds of the Tertiary sequence that will be seen tomorrow in the White Lake Basin, 50 miles (80 km) to the northwest.

West of Stop 7:6 the excursion climbs the west side of the fault-controlled Kettle Valley through Eocene sandstone and alkaline-trachyte dykes and sills (some of which are rhomb-porhyry) that are feeders to the basal Eocene flows. On the plateau at the top are scattered exposures of the Anarchist Group, which comprises upper Paleozoic greenstone, chert, and argillite, with a low grade of regional metamorphism. These rocks are similar to the Kobau Group west of the Okanagan Valley.

Stop 7:7 (Mile 147.3, Km 235.7) Lookout, Anarchist Mountain

This stop is on Mesozoic migmatites and provides an excellent view of the Okanagan Valley, a fault-controlled feature, the floor of which is only 900 feet (275 m) above sea level. To the north, the east side of the Okanagan Valley is underlain by gneiss similar to that of the Grand Forks Group. The west side of the valley is underlain by upper Paleozoic low-

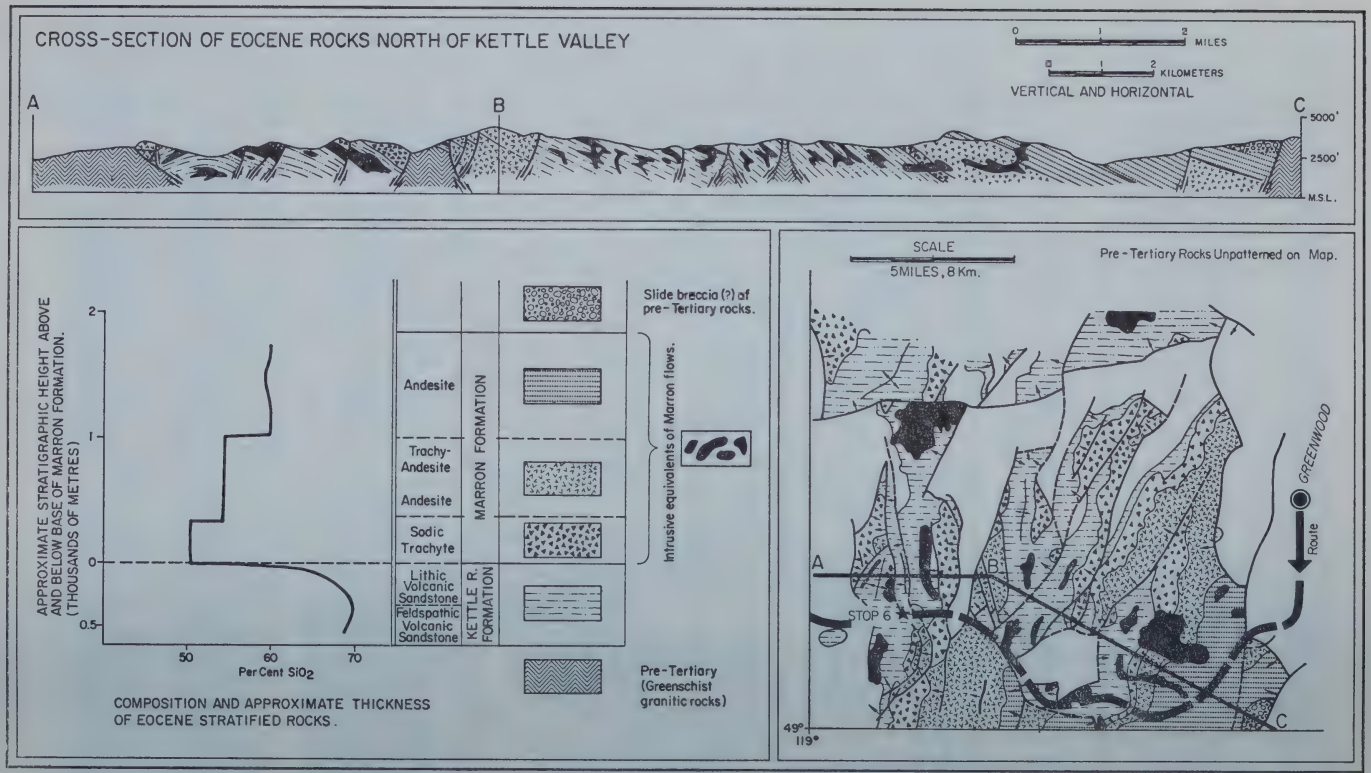


Fig. 7:2. Tertiary structure and stratigraphy west of Greenwood, B.C.

grade rock similar to the Anarchist Group, Mesozoic granite, and Eocene volcanic rocks. The valley floor is occupied largely by Quarternary glacial and post-glacial deposits (Nasmith, 1962).

The Lower Tertiary and Basement Rocks of the Okanagan Valley

by B. N. Church, B. C. Department of Mines and Petroleum Resources

General Geology

The excursion on Day 8 covers the area to the northwest of Osoyoos. The emphasis is on the Tertiary rocks, with brief reference to the pre-Tertiary basement.

The Tertiary rocks are deeply eroded and present an ideal cross-section of one of the deep fault-bounded basins filled with Tertiary sedimentary and volcanic rocks found throughout the interior of British Columbia (Figure 8:1). They consist of five main stratigraphic divisions; from base to top:—

1) the Springbrook Formation, discontinuous beds of talus and basal conglomerate;

2) the Marron Formation, a thick and widely distributed succession of volcanic rocks of diverse composition — mainly phonolite, trachyte, and andesite lavas;

3) the Marama Formation, discontinuous volcanic beds — mainly rhyodacite lava;

4) the White Lake Formation, locally thick volcanic sandstone and conglomerate beds intercalated with lahar and pyroclastic deposits;

5) the Skaha Formation, local deposits of slide breccia and some volcanic rock overlain by fanglomerate beds.

Each stratigraphic division was deposited unconformably on older rocks, and the total accumulated succession has a maximum aggregate thickness of about 12,000 feet (3650 m).

In general, the Tertiary assemblage is down-faulted and tilted to the east forming a trap-door-like structure. Greatest downward movement is near the Okanagan Valley where it is estimated that basal beds are as much as 5,000 feet (1500 m) below sea level. Folds are developed in areas of thick accumulation but appear to be without regional pattern and probably reflect faulting of basement rocks.

Petrographic and chemical analyses of the volcanic suite show a peculiar mixture of siliceous, intermediate, and undersaturated alkaline magma types such as rhyolite, andesite, phonolite and mafic phonolites. In regional perspective, the silicic and intermediate suite appears to be part of a discontinuous andesite volcanic belt trending meridionally through central British Columbia, western Washington and Oregon. The alkaline volcanic suite seems to be genetically related to the Coryell plutonic intrusions farther east. Together, these rocks form a distinctive petrographic province similar in many ways to the Highwood petrographic province east of the Rocky Mountain divide in central Montana (*see* Figure 8:2).

Pre-Tertiary metamorphic rocks are well displayed on the highway east of the Similkameen River and near Vaseaux Lake. They are the greenschist-grade Kobau Group and gneisses similar to those of the Shuswap Metamorphic complex. A recent study by Okulitch (1967) indicates that the Kobau Group, consisting mainly of siliceous metasediments, may be correlative with the upper part of the Shuswap Metamorphic complex, although relative ages are uncertain. These rocks apparently underwent several periods of folding, with early recumbent folds and superposition of two sets of cross-folds. The main folds are dislocated by Tertiary faulting. Mile 0 is at the junction of Highway 3 and 97.

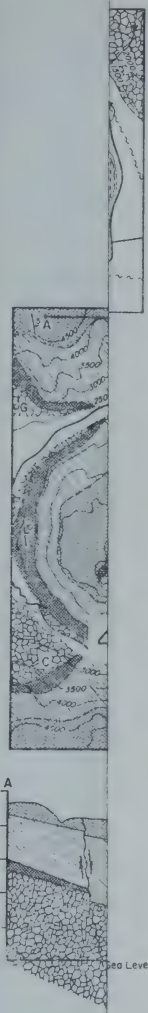
Day 8

Stop 8:1 (Mile 3.4, Km 5.4) Spotted Lake, salt deposits

Spotted Lake is a small ephemeral body of water with encrusted salt deposits formed as a result of ground water leaching and evaporating in a semi-arid climate. The salt is composed of about equal amounts magnesium sulphate and sodium sulphate with minor sodium carbonate and calcium sulphate. The peculiar ring structures are thought to be caused by surface stress resulting from alternate flooding and drying of the lake and crystallization of the salt.

Stop 8:2 (Mile 20, Km 32) Kobau metasediments

Siliceous argillite and metaquartzite, well exposed in this road cut, are typical of the main unit of the Kobau Group, similar to many rocks of the Anarchist Group east of the Okanagan Valley. Minor phases include thin bands of marble and greenstone to the east. The pelitic rocks have attained the biotite-garnet grade of regional metamorphism and most units show evidence of cataclasis. Bedding planes and axial plane foliation are thought to be locally coincident, and both dip steeply to the west at this locality.



LEGEND

EARLY TERTIARY ROCKS

SKAHA FORMATION
UPPER MEMBER : MIXED BOULDER CONGLOMERATE.
LOWER MEMBER : MAINLY GRANITE, CHERT, AND GREENSTONE SLIDE BRECCIAS WITH INTERCALATED CONGLOMERATE AND SOME AUGITE - PORPHYRY (TEPHRITE) LAVA

WHITE LAKE FORMATION
MUDSTONE, SANDSTONE, CONGLOMERATE, COAL, AND MINOR PYROCLASTIC ROCKS INTERCALATED WITH TRACHYTE AND TRACHYANDESITE VOLCANIC BRECCIA, PYROCLASTIC ROCKS, AND LAHAR.

MARAMA FORMATION
UNDIVIDED RHYODACITE AND RHYOLITE LAVA, SOME VOLCANIC BRECCIA AND PYROCLASTIC ROCK AND MINOR BASAL CONGLOMERATE.

MARRON FORMATION

PARK RILL MEMBER MAINLY MEROCRYSTALLINE AND VITRIC ANDESITE LAVA

NIMPIT LAKE MEMBER MAINLY ROSETTE PORPHYRY, SANIDINE - PLAGIOCLASE BEARING TRACHYTE LAVA.

KEARNS CREEK MEMBER MAINLY PYROXENE PORPHYRY, VESICULAR BASALTIC ANDESITE LAVA

KITLEY LAKE MEMBER : MAINLY CLOT PORPHYRY, SANDINE – PLAGIOCLASE BEARING TRACHYTE AND TRACHYANDESITE LAVA

YELLOW LAKE MEMBER RHOMB PORPHYRIES, AUGITE - ANORTHOCLASE LAVA, VOLCANIC BRECCIA, AND PYROCLASTIC ROCK.

SPRINGBROOK FORMATION
PEBBLE AND BOULDER CONGLOMERATE, BRECCIA, AND SANDSTONE.

PRE - TERTIARY ROCKS

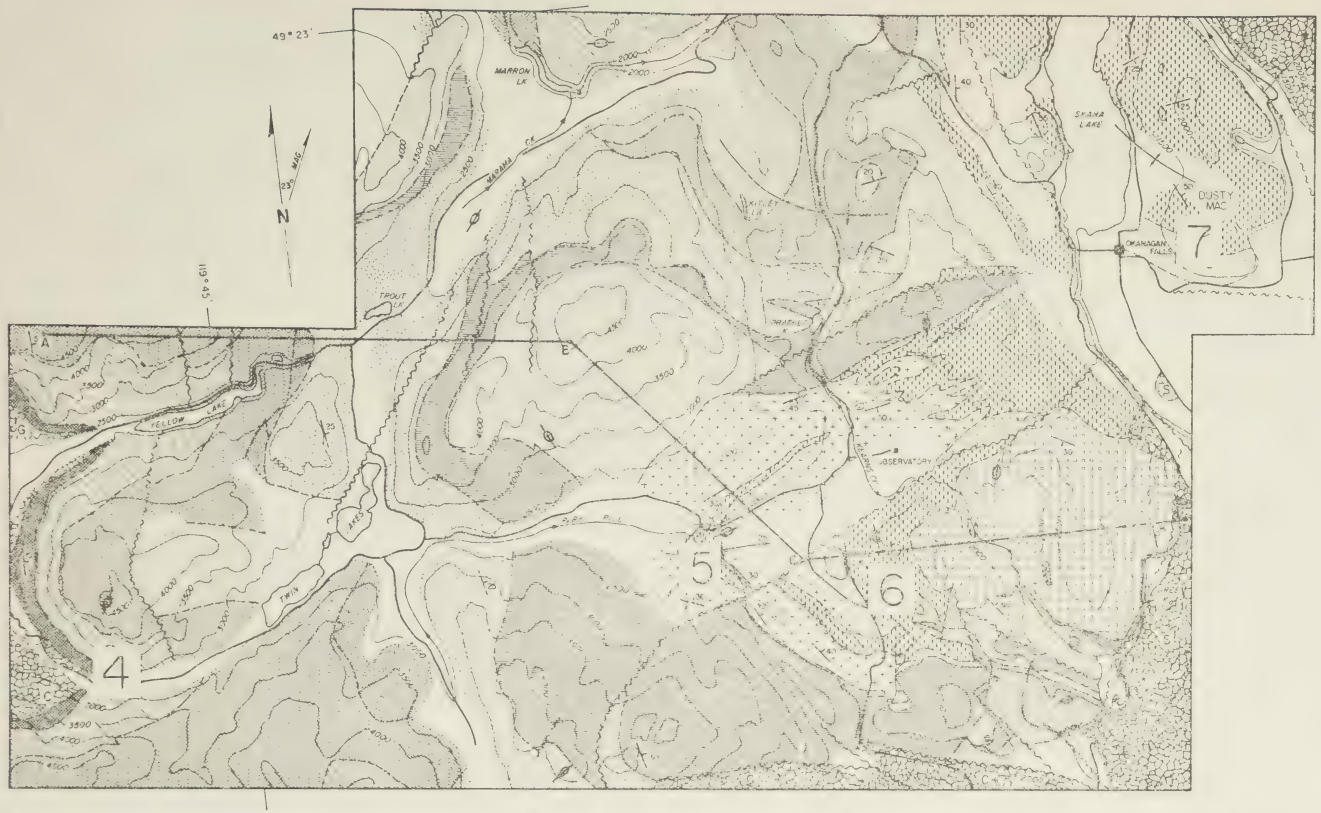
G - OLD TOM FORMATION : MAINLY GREENSTONE.
C - SHOEMAKER FORMATION : MAINLY CHERT
S - SHUSWAP FORMATION : GNEISSIC BASEMENT COMPLEX.

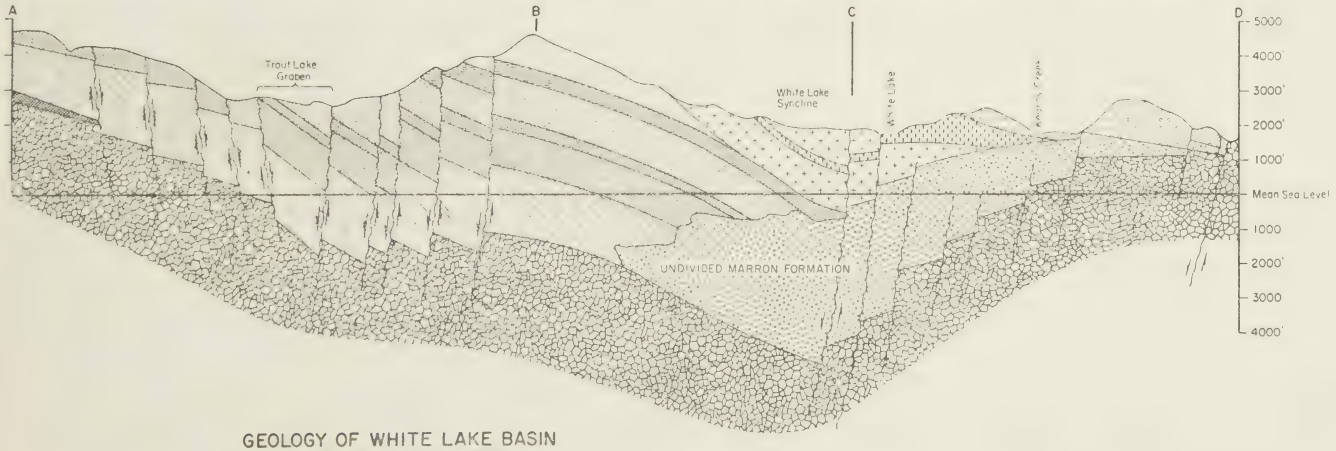
SYMBOLS

BEDDING ATTITUDE
ANTICLINAL AXIS
SYNCLINAL AXIS
GEOLOGICAL CONTACT
FAULT ZONE
BOUNDARY OF BEDROCK EXPOSURE
2000 — TOPOGRAPHIC CONTOUR, 500' INTERVAL
ROAD
A — B POSITION OF STRUCTURE SECTION
GLACIAL STRIAE

5 - STOPS

Figure





GEOLOGY OF WHITE LAKE BASIN

GEOLOGY BY - N. CHURCH, 1970

SCALE - MILES

SCALE - Km

LEGEND

EARLY TERTIARY ROCKS

SKAHA FORMATION
UPPER MEMBER: MIXED BOULDER CONGLOMERATE.
LOWER MEMBER: MAINLY GRANITE, CHERT, AND GREENSTONE SLIDE BRECCIAS WITH INTERCALATED CONGLOMERATE AND SOME AUGITE-PORPHYRY (TEPHRITE) LAVA

WHITE LAKE FORMATION
MUDSTONE, SANDSTONE, CONGLOMERATE, COAL, AND MINOR PYROCLASTIC ROCKS INTERCALATED WITH TRACHYTE AND TRACHYANDESITE VOLCANIC BRECCIA, PYROCLASTIC ROCKS, AND LAHAR.

MARAMA FORMATION
UNDIVIDED RHYODACITE AND RHYOLITE LAVA, SOME VOLCANIC BRECCIA AND PYROCLASTIC ROCK AND MINOR BASAL CONGLOMERATE.

MARRON FORMATION

PARK RILL MEMBER: MAINLY MEROCRYSTALLINE AND VITRIC ANDESITE LAVA

NIMPIT LAKE MEMBER: MAINLY ROSETTE PORPHYRY, SANIDINE-PLAGIOCLASE BEARING TRACHYTE LAVA.

KEARNS CREEK MEMBER: MAINLY PYROXENE PORPHYRY, VESICULAR BASALTIC ANDESITE LAVA

KITLEY LAKE MEMBER: MAINLY CLOT PORPHYRY, SANDINE-PLAGIOCLASE BEARING TRACHYTE AND TRACHYANDESITE LAVA

YELLOW LAKE MEMBER: RHOMB PORPHYRIES, AUGITE-ANORTHOCLASE LAVA, VOLCANIC BRECCIA, AND PYROCLASTIC ROCK.

SPRINGBROOK FORMATION
PEBBLE AND BOULDER CONGLOMERATE, BRECCIA, AND SANDSTONE.

PRE-TERTIARY ROCKS

G - OLD TOM FORMATION: MAINLY GREENSTONE.
C - SHOEMAKER FORMATION: MAINLY CHERT
S - SHUSWAP FORMATION: GNEISSIC BASEMENT COMPLEX.

SYMBOLS

- BEDDING ATTITUDE
- ANTICLINAL AXIS
- SYNCLINAL AXIS
- GEOLOGICAL CONTACT
- FAULT ZONE
- BOUNDARY OF BEDROCK EXPOSURE
- TOPOGRAPHIC CONTOUR, 500' INTERVAL
- ROAD
- POSITION OF STRUCTURE SECTION
- GLACIAL STRIAE

5 - STOPS

Figure 8:1

British Columbia Department of Mines and Petroleum Resources.

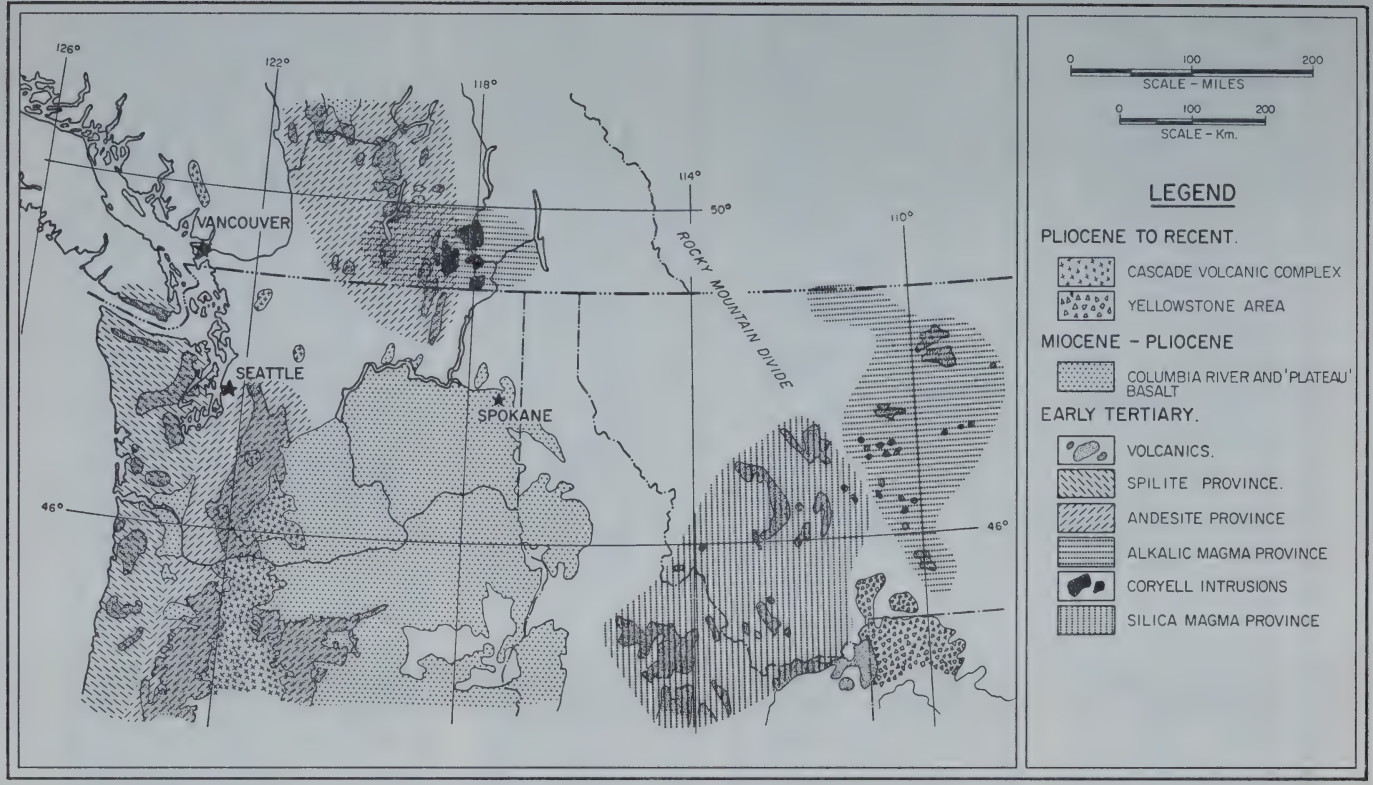


Fig. 8:2. Cenozoic petrographic regions of southern British Columbia and the northwestern United States.

Stop 8:3 (Mile 40, Km 64) Springbrook Formation

The Springbrook Formation is well displayed on bluffs east of Keremeos Creek above the highway. The unit is about 700 feet thick (230 m) and consists of dark chert breccia in the lower part overlain by well-layered pebble and boulder conglomerate. The fragments were eroded from pre-Tertiary beds of feldspathic andesite, grey and black chert, argillite, chlorite schist and gneiss. These rocks are down-faulted slightly and tilted gently to the east.

Stop 8:4 (Mile 41, Km 65.5) Base of the Marron Formation, rhomb-porphyries

The lowermost part of the Marron Formation is exposed about 300 feet (90 m) north of the road entering the west end of the White Lake basin. The lowest unit, composed of porphyritic phonolite lava and pyroclastic rocks, is intercalated with upper Springbrook conglomerate. The volcanic rocks are normally zeolite-bearing, containing minerals such as natrolite, analcite, laumontite-leonhardite, mordenite, thomsonite and brewsterite.

Locally the rocks are severely weathered and show hoodoo structures and spheroidal pits on cliff faces.

Columnar jointed rhomb porphyry dykes are fresh and well exposed. These rocks carry distinctive rhomb-shaped anorthoclase phenocrysts similar to the Tertiary dykes and sills near Rock Creek, described by Daly (1912). Chemical analyses of these rocks show an unusually high alumina, alkali, and alkali-earth content.

Stop 8:5 (Mile 46.5, Km 74.4) Panorama of White Lake Basin

A resistant band of White Lake conglomerate, 200 feet (60 m) south of the main road, forms an excellent vantage point overlooking the hollowed-out core of the White Lake syncline. A view to the southeast shows the south limb of the syncline, composed mainly of soft sedimentary rocks, warped downward to meet a line of high bluffs of lahar beds just beyond White Lake. To the southeast, the sediments of the White Lake Formation onlap andesites that are the uppermost unit of the Marron Formation. The ridges and benches beyond, farther west, are successive trachyte and trachyandesite flows which are the conformable middle members of the Marron Formation.

Stop 8:6 (Mile 50.5, Km 80.7) Skaha Formation at Indian Head

Indian Head is a conspicuous erosional remnant one half mile east of White Lake. The Skaha breccias consist of highly comminuted dark chert and greenstone forming a cap on little-disturbed White Lake tuff breccia and agglomerate. Here the breccia is near the projected western edge of a massive slide breccia complex that underlies the ridge immediately east of Indian Head and Mt. Hawthorn.

Stop 8:7 (Mile 62.5, Km 100) Dusty Mac prospect

This mining prospect is one mile (1.6 km) east of Okanagan Falls. Mineralization consists of free gold and silver in a quartz breccia zone. The deposit is lens-shaped and appears to be associated with reverse faulting on the south limb of a southeasterly-trending syncline. The host rocks, consisting mainly of White Lake lahar beds, have been thrust outward and upward from the axis of the syncline in response to concentric folding. Fissures and dilations resulting from this movement provided access to siliceous ore-bearing solutions. Recurrent movement caused brecciation of quartz veins and lenses, and some dispersal of the ore.

Stop 8:8 (Mile 65.0, Km 106) Gneiss of Shuswap complex

The coarsely layered lower section of gneiss correlative with the Shuswap complex is well exposed in road cuts immediately northeast of Vaseaux Lake. This rock is medium to coarse-grained gneiss and consists of dark layers of amphibole and feldspar alternating with light-coloured layers of biotite, feldspar and quartz. Except for local swirls and augen structures the gneissosity is typically sub-horizontal.

Interior Plateau to Cascade Mountains

by V. A. Preto, B. C. Department of Mines and Petroleum Resources

General Geology

West of Osoyoos the regional, pre-Tertiary structure is poorly known, but there is a general, progressive decrease in age of the stratified rocks from east to west, until the Cascade Mountains are reached. The Carboniferous (?) Kobau Group between Osoyoos and Keremeos is replaced progressively by Permo-Triassic, Upper Triassic and Jura-Cretaceous strata. Intruding these are Upper Triassic and younger grani-

tic plutons of various sizes. Middle Eocene volcanic and sedimentary rocks are widespread and unconformably overlie all pre-Tertiary formations. At Princeton, and 11 miles (17.6 km) northwest at Coalmont, the Tertiary strata form two large basins, the upper, sedimentary parts of which are coal bearing. The Princeton basin is the larger of the two and is elongated in a northerly direction along a zone of considerable block faulting. Its origin is probably in part related to this system of faults, some of which cut the youngest rocks in the basin. The Triassic strata are very important economically, as they contain significant copper and gold deposits and are thus in contrast to the Proterozoic and Lower Paleozoic strata to the east with their silver-lead-zinc ores. Mile 0 is at the junction of Highways 3 and 97.

Day 9

Stop 9:1 (Mile 30.7, Km 49.1) Permo-Triassic strata, east end of Similkameen Valley

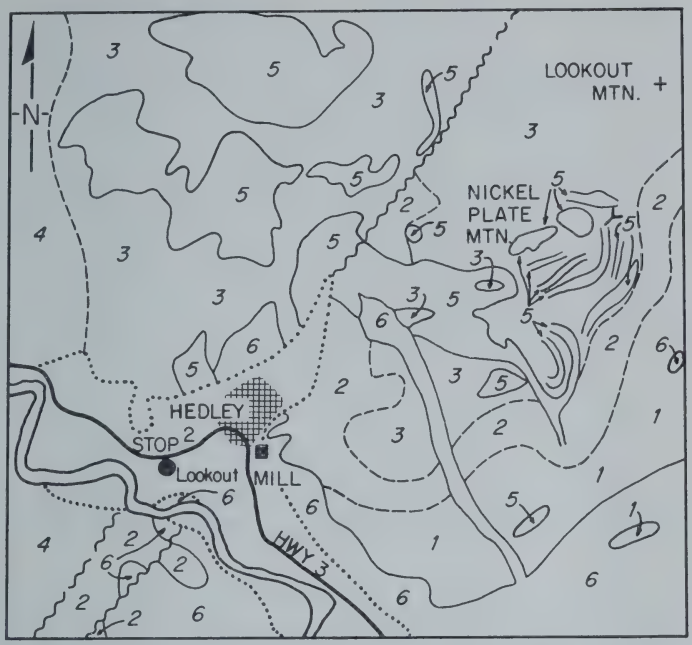
The Similkameen Valley is the physiographic boundary between rocks of the Cascade Mountains, to the south, and the Interior Plateau, to the north. Of note are the enormous talus slopes along the valley. This area was unglaciated during the last glacial episode (Figure 1:4) and hence these talus piles accumulated for a long time.

Bedded cherts and massive altered basic lava and greenstone are well displayed at this stop. This lithological assemblage is typical of upper Paleozoic to mid-Triassic rocks in the Intermontane Belt.

On the way to Stop 9:2, a layer of white volcanic ash is visible in the soil on both sides of the road. It was erupted from Mount Mazama, Oregon, U.S.A., 6,600 years ago. Between Mile 43 and Stop 9:2 is massive granodiorite of Jurassic or younger age.

Stop 9:2 (Mile 48.2, Km 77.1) Upper Triassic sedimentary rocks and Hedley Gold Mine at Hedley Lookout

The sedimentary rocks at Hedley are of Late Triassic age and form the lower part of the Nicola Group (Figure 9:1). They consist of a lower unit of limestone, cherty quartzite and argillite, overlain by limestone, quartzite, argillite and conglomerate, and finally well-bedded black argillite, tuff and impure limestone. This sedimentary sequence is overlain to the west by a volcanic sequence of andesite, basalt, breccia and tuff, also of Upper Triassic age. At Hedley, these strata are intruded by two small bodies of Jurassic diorite and gab-



JURASSIC OR YOUNGER

6 GRANODIORITE

5 DIORITE, GABBRO

UPPER TRIASSIC

4 HENRY FM. – BLACK ARGILLITE, TUFF, IMPURE LIMESTONE.

3 HEDLEY FM. – LIMESTONE, QUARTZITE, CHERTY QUARTZITE, ARGILLITE, CONGLOMERATE, BRECCIA, TUFF.

2 SUNNYSIDE FM. – LIMESTONE.

1 REDTOP FM. – LIMESTONE, CHERTY QUARTZITE, SILICEOUS ARGILLITE, TUFF, SOME BRECCIA.

Fig. 9:1. Geology in the vicinity of Hedley.

bro, from which many sills and dykes emanate, and by a younger, but probably also Jurassic, granodiorite which truncates the lower units of the sedimentary succession. The beds dip moderately to the northwest, as does the granodiorite contact. The Nickel Plate gold mine, of which the ruined concentrator plant can be seen, produced 1.3 million ounces of gold between 1896 and 1930, when the mine temporarily closed. A thorough geological study gave the mine a second life, and 1.7 million ounces of gold were produced between 1934 and 1958, when mining finally ended. Ore shoots occur in garnet-pyroxene skarn produced by contact metamorphism of a limestone, and are generally less than 250 feet (75 m) from the outer edge of the skarn zone (marble line). Their size and shape is controlled by crumples in the skarn and by intersections of sills and dykes, which are offshoots from the diorite and gabbro instrusions. The metallic minerals in the Nickel Plate skarn are: arsenopyrite, lollingite-safflorite, cobaltite, pyrrhotite, sphalerite, chalcopyrite, gold, pyrite and marcasite. Of these, arsenopyrite is the most abundant and important as most of the gold occurs as minute specks in it.

Between here and Stop 9:3 the excursion follows the highway to Princeton and traverses an area mainly underlain by Jurassic plutonic rocks flanked to the west by Upper Triassic volcanic rocks and then middle Eocene volcanic rocks which are part of the Princeton Tertiary Basin. It then turns south along the eastern side of this basin to Copper Mountain.

Stop 9:3 (Mile 85.1, Km 136.2) Copper Mountain Mine

The mineral deposits of Copper Mountain are on the northeast side of an elongated, 197 m.y. old, concentrically-differentiated stock which is part of a continuous alkalic-calcic rock series ranging in composition from pyroxenite to perthosite pegmatite. The series is believed to have been derived by crystal differentiation from single parent magma of basic diorite composition (Montgomery, 1967). The copper deposits are chiefly in a narrow belt of altered Upper Triassic andesitic volcanic rocks sandwiched between the main stock to the southwest and a satellitic monzonite-syenite complex to the northeast (Figure 9:2). Rock alteration near the deposits include formation of biotite hornfels, extensive albitization and chlorite-epidote alteration, potash feldspar metasomatism and introduction of calcite-biotite-potash feldspar-sulphide-bearing pegmatite veins and dykes. The mineral deposits consist essentially of fracture fillings by pyrite, chalcopyrite,

and, in places, bornite in favourably altered volcanic rocks at structurally suitable locations. The pit visited at this stop is located at the centre of a newly outlined ore zone being prepared for mining. Typical alteration and mineralization of the volcanic rock, some of which preserves original textures, are displayed in the open pit, as well as several large faults, sulphide-bearing pegmatite veins, post-mineral felsite dykes and, in the northeast corner of the pit, a pipe of mineralized intrusive breccia that is a border phase of the monzonite-syenite complex found to the north. Former production from this pit has been approximately 1.7 million tons of ore grading .7% Cu. Total production at the Copper Mountain mine until 1957 was 613.14 million lbs. of copper, 187,294 ounces of gold, 4.38 million ounces of silver from 34.775 million tons of ore mined.

Stop 9:4 (Mile 112.8, Km 180.5) Copper Mountain Lookout and Ingerbelle Mine

The excursion passes through the town of Princeton, where there are exposures of massive, cross-bedded sandstone of Eocene age. These are part of an assemblage of continental clastic and volcanic rocks in the Tertiary Princeton basin. Coal was mined from this basin for many years.

South of the Tertiary basin are mainly Upper Triassic volcanic rocks with a few small outliers of Tertiary volcanics. Stop 9:4 offers a view of Copper Mountain across the Similkameen River to the southeast where the northeastern contact of the Copper Mountain stock and old mine workings can be seen. Farther to the north are Middle Eocene intrusive and volcanic rocks. The Ingerbelle mine nearby is a recent operation developed on an orebody somewhat similar to those of Copper Mountain. Unlike at Copper Mountain, rock alteration at Ingerbelle is typified by extensive scapolite veining and by more intricate and extensive replacement and veining by pink sodic plagioclase and potash feldspar. To reach the Lookout, procede north along the old highway for 1.9 miles (3 km) from mile point 112.8.

Stop 9:5 (Mile 127.9, Km 211.0) Similkameen Falls

The Similkameen River is a superimposed stream that cuts through glacial deposits into Upper Triassic volcanic rocks of the Nicola Group, forming a deep canyon. The Triassic rocks here consist of thinly-bedded waterlain tuff, massive crystal tuff, and intraformational tuff breccia with a crystalline matrix and slivers of black, cherty argillite. The strata trend 010 degrees, dip steeply, and probably face west. On

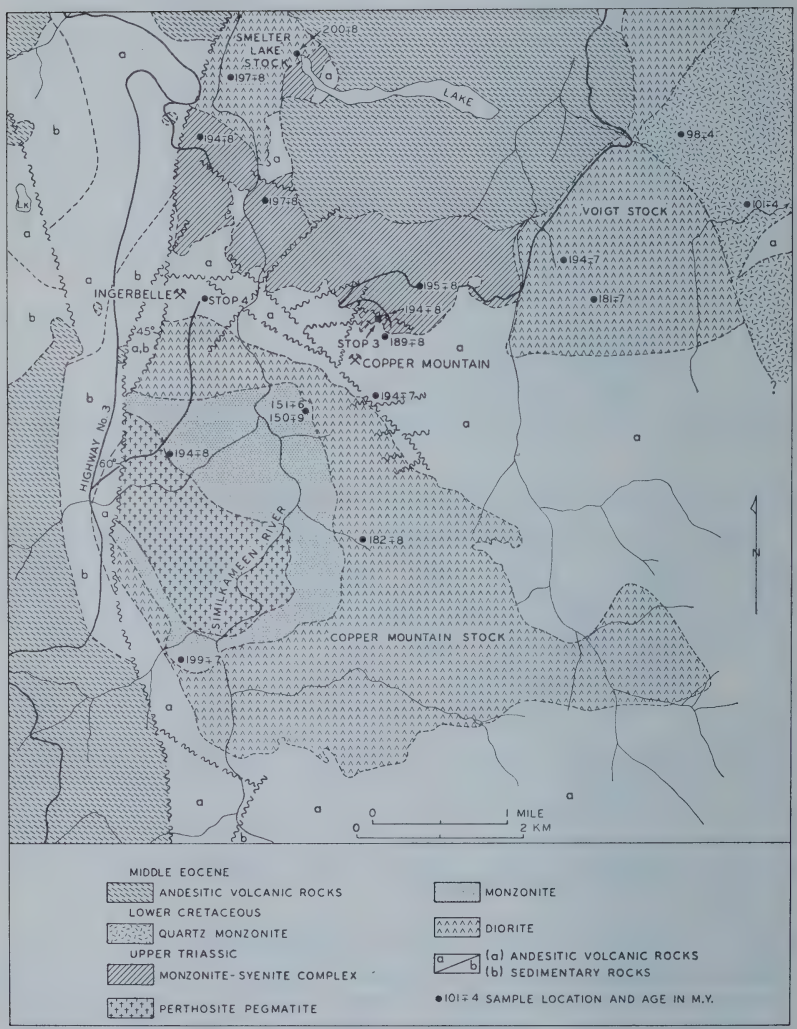
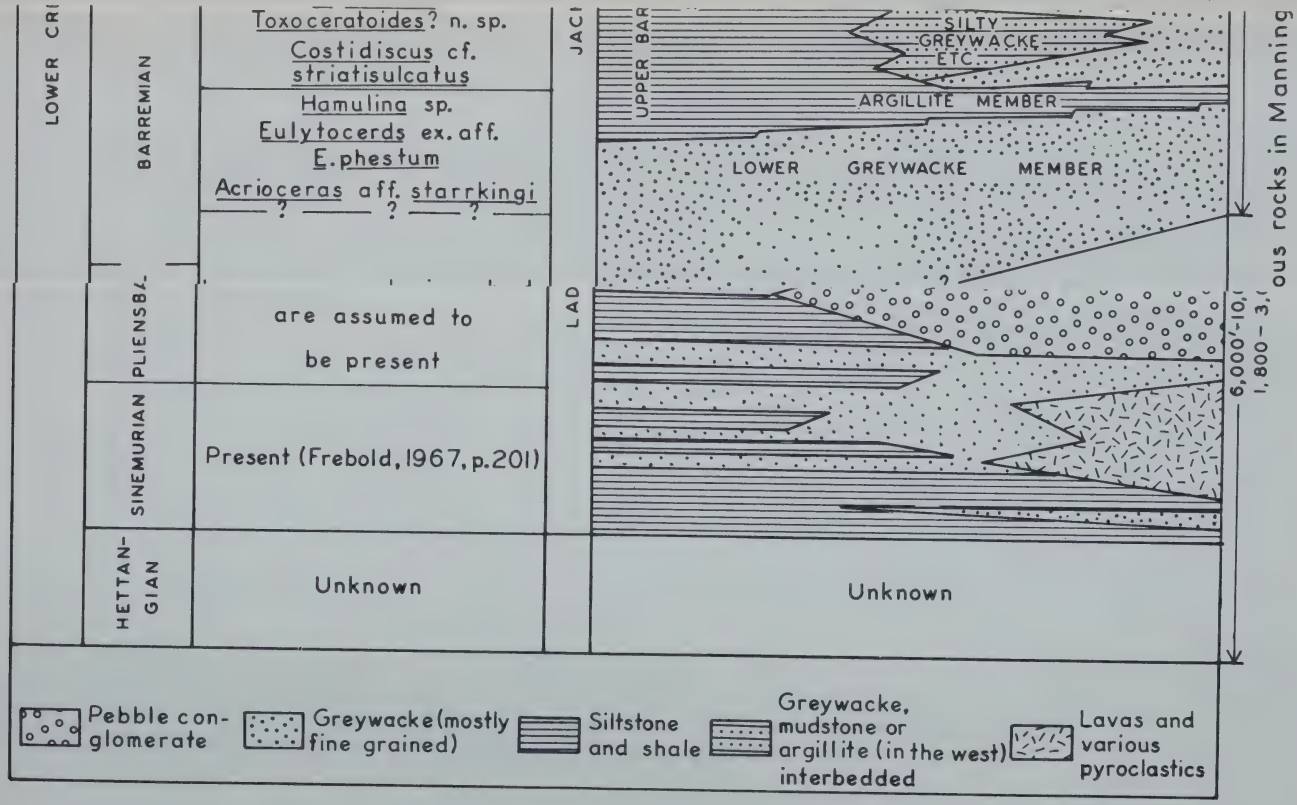


Fig. 9:2. Generalized geology of the Copper Mountain area, British Columbia.


LOWER CRI
BARREMIAN
Toxoceratoides? n. sp.
Costidiscus cf. striatisulcatus
Hamulina sp.
Eulytocerds ex. aff. E. phestum
Acrioceras aff. starrkingi
? ? ?
PLIENSB.
are assumed to be present
SINEMURIAN
Present (Frebold, 1967, p.201)
HETTAN-GIAN
Unknown
JACI
LAD
UPPER BAR
SILTY GREYWACKE ETC.
ARGILLITE MEMBER
LOWER GREYWACKE MEMBER
Unknown
6,000'-10,
1,800 - 3,
ous rocks in Manning
Pebble conglomerate
Greywacke (mostly fine grained)
Siltstone and shale
Greywacke, mudstone or argillite (in the west) interbedded
Lavas and various pyroclastics

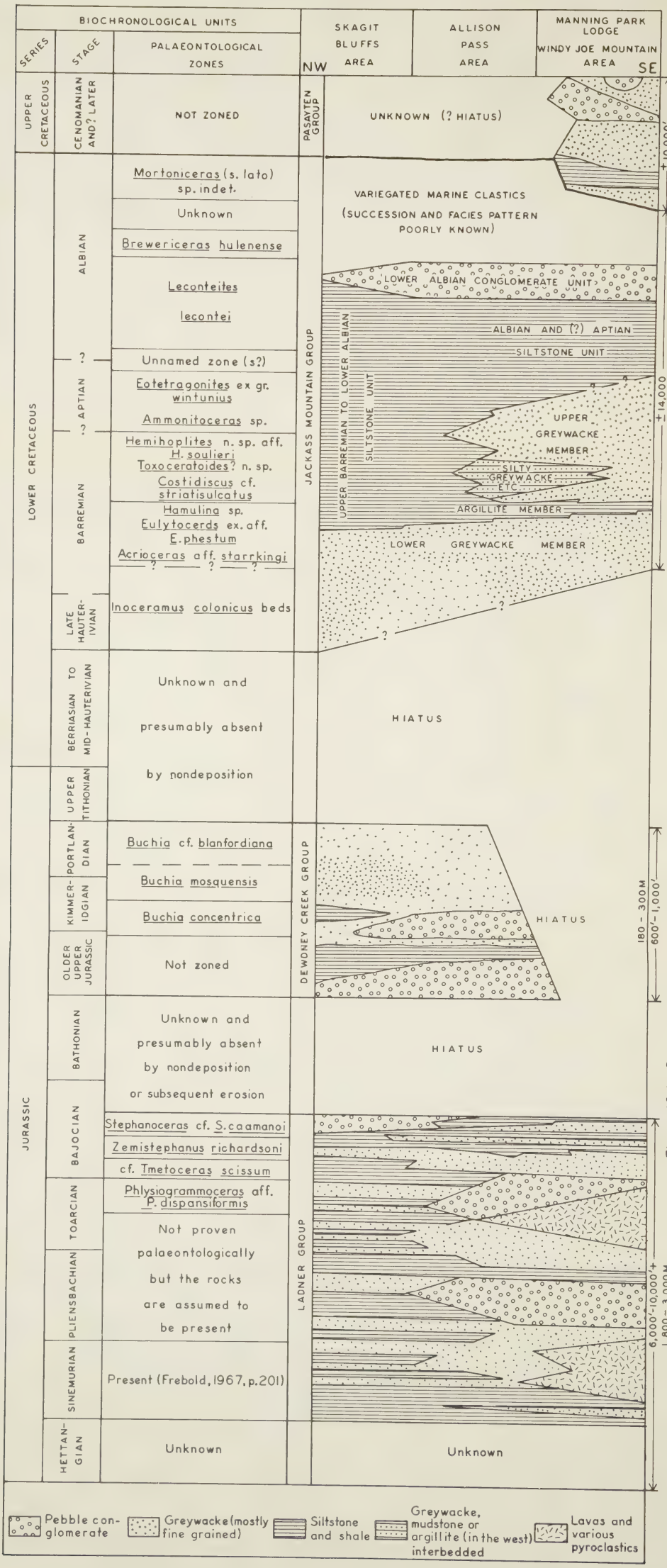


Figure 10-1. Suggested age and facies relationships of Jurassic and Cretaceous rocks in Manning Park

the way to Stop 9:6 the route traverses an area of poorly exposed Upper Triassic volcanic rocks which become rapidly more schistose towards a body of granodiorite gneiss, known as the Eagle Granodiorite complex.

Stop 9:6 (Mile 133.2, Km 233.1) Eagle Granodiorite complex

The Eagle Granodiorite complex is exposed in a narrow northwesterly elongated belt. It consists of a strongly foliated granodiorite and is bounded on the northeast by Upper Triassic volcanic and sedimentary rocks of the Nicola Group and on the southwest by Lower Cretaceous sedimentary rocks of the Pasayten Group. Northward it passes into foliated granodiorite that yields potassium argon ages of 143 and 98 m.y. Structures in the complex conform with those in the Upper Triassic rocks to the east, the contact being marked by a transition zone of increasing schistosity and metamorphic grade of the volcanic rocks toward the granodiorite complex. Inclusions and/or pendants of metavolcanic rocks are common in the Eagle Granodiorite. The western contact of the complex is abrupt and marked by the Pasayten Fault, a steeply dipping regional structure not exposed along the route followed. West of this fault, structures verge towards the east and can be related to the pattern of deformation in the Cascade system. At this stop gneiss granodiorite contains several inclusions of amphibolite and schist and is cut by dykes of garnetiferous pegmatite. Between here and Pinewoods Lodge are a few other exposures of gneissic granodiorite, followed to the west by Lower Cretaceous sedimentary rocks of the Pasayten and Dewdney Creek Groups.

Mesozoic Rocks of Manning Park Area

by J. A. Jeletzky, Geological Survey of Canada

General Geology

The Mesozoic rocks of Manning Park are restricted to a synclinorial, fault-bounded belt on the eastern side of the Cascade fold belt. The rocks in this belt, perhaps as much as 30,000 feet (9200 m) thick, accumulated in the Mesozoic Tyaughton Trough, and were recently subdivided into four groups (Coates, 1970, pp. 149-150, and this paper, Figure 10:1). They are largely marine with the exception of the uppermost Pasayten Group.

Oldest rocks are the Lower to early Middle Jurassic Ladner Group, whose base is not seen, and which has a thickness

of more than 6,000 feet (1800 m) (Frebold, 1967, Frebold et al, 1969, Coates, 1966, 1967, 1970). It outcrops in two northwest-trending belts, an indurated "distal" western one that is typical flysch (Stops 10:1, 10:2) and a less indurated eastern "proximal" belt that resembles the "conglomerate flysch" of Aalto and Dott (1970). The eastern facies contains some shallow and non-marine deposits (Stops 5, 6) (*see* Figure 10:2) with interbeds of primary pyroclastic rock and lava.

Unconformably above the western facies is the Upper Jurassic Dewdney Creek Group. It consists of as much as 1,000 feet (300 m) of sandstone and siltstone with local conglomerate that increases in abundance to the northeast.

The mid-to late Lower Cretaceous Jackass Mountain Group, as much as 14,000 feet (4,300 m) thick, exhibits a facies pattern similar to that of the Ladner Group (Jeletzky, 1970) (Stops 10:2, 10:3, 10:4). The basal beds record a gradual eastward to northeastward transgression of the Hauterivian to mid-Barremian sea over the bevelled surface of the Ladner and Dewdney Creek Groups, following a prolonged late Tithonian and early Neocomian period of emergence. The upper

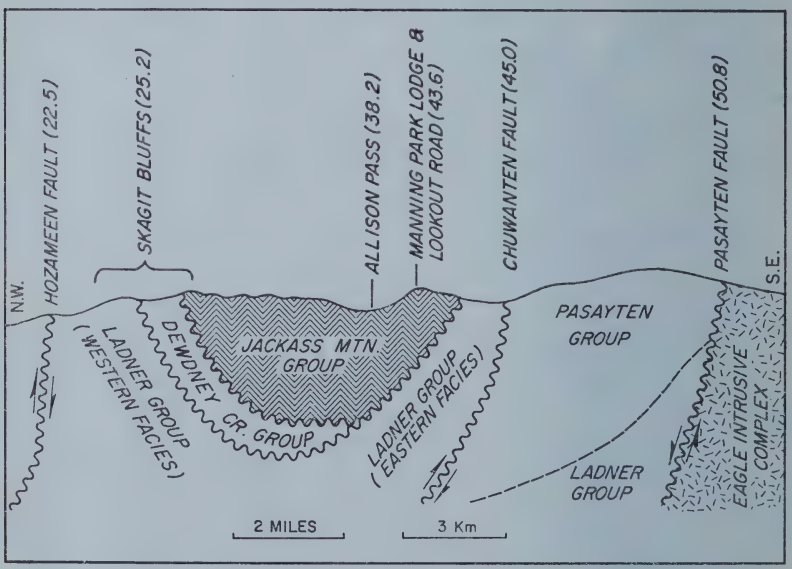
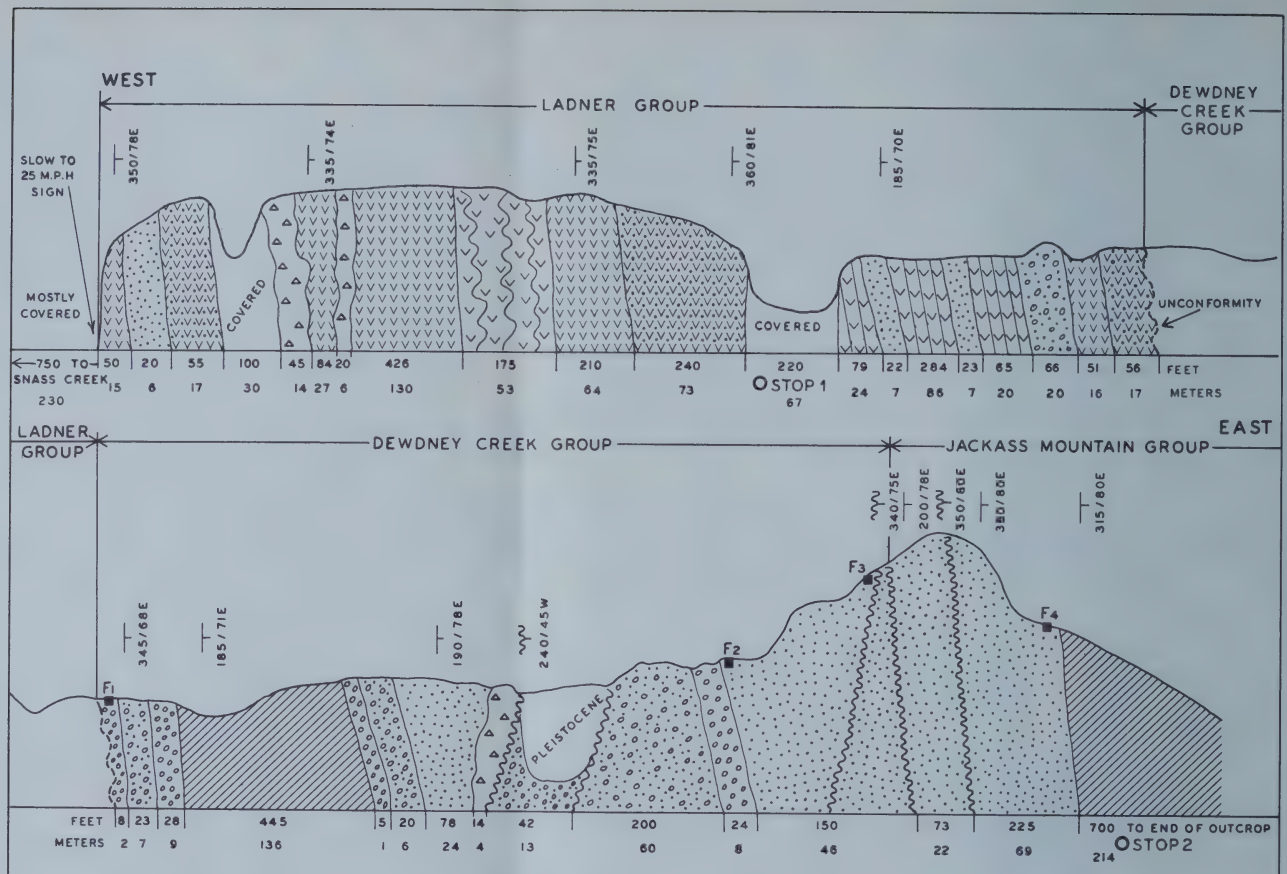


Fig. 10:2. Diagrammatic structure section across eastern part of the Cascade Fold belt in Manning Park.



- Argillite, mostly flinty and hard; minor intermediate to basic lava and tuff
- Argillite, with interbedded fine to coarse arenite and volcanic conglomerate; minor lava and tuff
- Argillite, slumped and brecciated
- Argillite, banded, very flinty; some arenaceous, conglomerate and tuffaceous interbeds
- Volcanic sandstone, locally tuffaceous
- Interbedded volcanic sandstone, grit and pebble conglomerate
- Pebble conglomerate; some interbeds of grit and pebbly sandstone
- Siltstone, sandy and thick bedded
- Intrusive dykes, acidic to basic
- 240/45W Fault, with attitude
- 190/78E Attitude of beds

FOSSIL LOCALITIES

F1 Cylindroteuthidid belemnites

F2 Buchia mosquensis (Buch) G.S.C. loc. 83955, 4 feet above base of unit

F3 Buchia mosquensis, Cylindroteuthis sp. G.S.C. loc. 83953 4.5 feet below fault

F4 Eulytoceras ex aff. phestum fauna. G.S.C. loc. 83952, 8 feet below top of unit

FIGURE 10:3 MESOZOIC SECTION ALONG SKAGIT BLUFFS; NORTH SIDE OF HOPE-PRINCETON HIGHWAY
(NOT TO SCALE)

beds are littoral or neritic in the east. In the west the beds were initially formed in a lower neritic environment but later were deposited in deeper water. The Albian part of the group includes much flysch, including "conglomeratic flysch" (see Stop 10:3). Like the Ladner and Dewdney Creek rocks before them, the Jackass Mountain rocks were derived from an eastern to northeastern source area.

The Pasayten Group, as much as 10,000 feet (3,050 m) thick, consists of arkosic rocks with minor conglomerates and siltstone (Stop 10:7). Albian marine fossils occur only in the lower part of the unit (Coates, 1967, p. 57) and above this are post-upper Albian red beds and conglomeratic arenite. The latter were derived from Paleozoic and Mesozoic rocks to the west. This change of source area (all older rocks were derived from the east; Coates, 1970, p. 151; Jeletzky, 1970, p. 223) records a regional uplift of the western Cascades and Coast Mountains resulting in the permanent emergence of the Tyaughton Trough at the end of the Albian or (?) later. The day begins with a non-stop drive from Pinewoods Lodge to the west of Skagit Bluffs.

Day 10

Stop 10:1 (Mile 18.5, Km 29.6) West end, Skagit Bluffs, Ladner and Dewdney Creek Groups

Rhythmically alternating, thin bedded argillite and fine-grained, graded volcanic sandstone and minor silicified tuff of the western facies of the Ladner Group forms the western part of Skagit Bluffs (*see* Figure 10:3). These rocks become younger to the east, and pass upward after about ¼ mile (0.4 km) through a disconformable contact into the Dewdney Creek Group, which consists of shallow water conglomerates and grits.

From Stop 10:1 to the eastern end of Skagit Bluffs (about ¾ mile, 1.2 km) is a section about 1,000 feet (300 m) thick of the Dewdney Creek Group and the basal part of the Jackass Mountain Group (*see* Figure 10:3).

Stop 10:2 (Mile 19.2, Km 30.7) East end, Skagit Bluffs

Argillaceous rock of the lower part of the Jackass Mountain Group is exposed at this locality. To the west is the contact between the Jackass Mountain and Dewdney Creek Groups, in a succession of strongly indurated, fine-grained sandstone. Paleontological and regional-structural grounds are the only evidence of a prolonged hiatus and unconformity.

The stretch of Hope-Princeton highway between Skagit Bluffs and Manning Park Lodge is underlain by folded, locally strongly faulted and contorted argillite, greywacke and conglomerate of the Jackass Mountain Group (*see* Figure 10:2).

Stop 10:3 (Mile 39.0, Km 62.4) Lookout Road, north of Manning Park Lodge, Jackass Mountain Group

The basal 200 feet (60 m) of the Lower Albian conglomerate unit of the Jackass Mountain Group is exposed at the second switchback of the Lookout Road (Figure 10:4). Graded bedding and the rare presence of ammonites and deep water pelecypods indicates that these conglomerates are proximal turbidites derived from an eastern shelf zone. The underlying thinly-bedded to laminated argillaceous rocks are distinctly graded and locally sole-marked. These are early Albian and (?) Aptian turbidites about 900 feet (270 m) thick and contain *Brewericeras (Leconteites) lecontei* and *Aucellina* ex. aff. *A. gryphaeoides* (Sowerby) about 140 feet (45 m) stratigraphically below the base of the conglomerate.

Stop 10:4 (Mile 39.8, Km 63.7) Lookout Road, Jackass Mountain Group

A section of the Barremian to Aptian greywacke unit is exposed at this locality (Figure 10:4). That these rocks are of predominantly neritic, littoral and beach origin is indicated by the abundance of fossil wood, irregular bedding, common crossbedding and ripple-marks, and the presence of coquina layers rich in shallow-water pelecypods and gastropods.

The argillite member at the base of the section is a 165-foot (55 m) thick tongue of the argillaceous offshore facies of the Jackass Mountain Group as seen in the western part of the area (*see* Figure 10:1 and in description of Stop 10:2).

Stop 10:5 (Mile 40.9, Km 65.5) Lookout Road, Ladner Group

The roadcuts below the Lookout expose a section about 400 feet (120 m) thick, representative of upper beds of the eastern facies of Ladner Group (*see* Figure 10:4). Unlike the correlative upper beds of the western facies of Ladner Group (*see* Stops 10:1, 10:2), those of the eastern facies are dominated by coarse to fine-grained arenites and rudites poor or lacking in features diagnostic of "distal" turbidites and locally exhibiting features suggestive of shallow water to non-marine origin. These rocks may be in part comparable with the "proximal" turbidites or fluxoturbidites (Dzulynski and others, 1959, p. 1114).

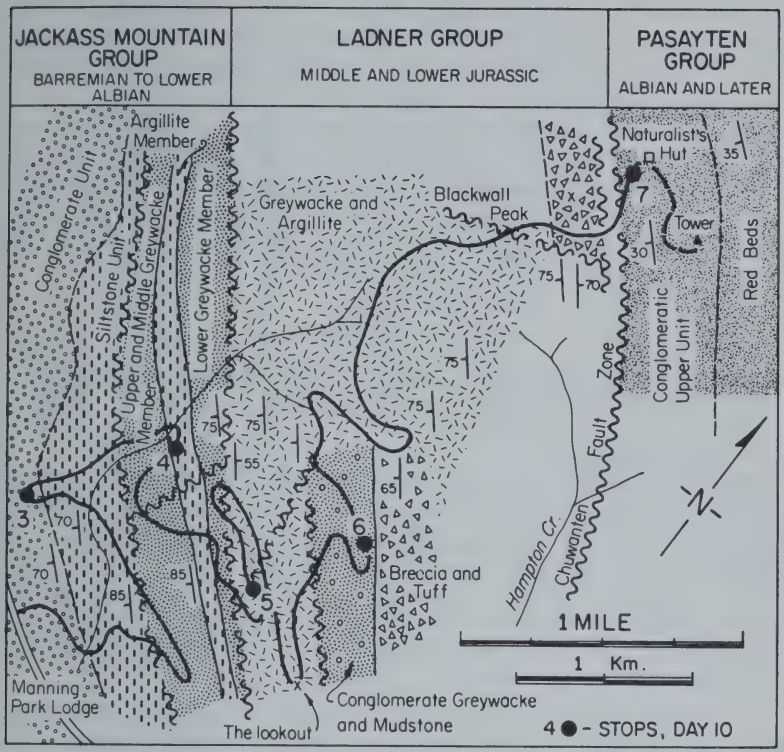


Fig. 10:4. Geological sketch map of the Mesozoic rocks on Lookout Road.

From the Lookout there is an unique panorama of the Cascade Mountains toward the east and the south.

Stop 10:6 (Mile 43.3, Km 69.3) Lookout Road, Ladner Group

The middle part of the eastern facies of the Ladner Group, at this locality about 920 feet (280 m) thick, is exposed on the Lookout Road (Figure 10:4). These beds differ from the upper beds seen at Stop 10:5 mainly in their content of andesitic pyroclastics and flows. These volcanics are believed to be local lens-like bodies that issued from nearby volcanic centers (Coates, 1970, p. 150). Above the volcanics are predominantly conglomeratic to coarse arenaceous, locally strongly tuffaceous sediments that appear to be mostly shallow water, beach and non-marine deposits.

The road cuts between the lower parking lot and the naturalist's hut in the alpine meadows expose about 630 feet

(190 m) of the upper part of the Pasayten Group. These rocks are irregularly bedded and poorly sorted, coarse to medium grained, locally pebbly, non-marine, carbonaceous arkose and greywacke devoid of marine fossils.

On the crest of the rounded ridge east of the naturalist's hut are older beds of this molasse-like upper unit of the Pasayten Group. The red coloured, arenaceous to argillaceous middle unit of the Pasayten Group is exposed on the slope east of this ridge (Figure 10:4). Albian ammonites are known from about 4½ miles (7 km) to the north.

Cascade Fold Belt

by K. C. McTaggart, University of British Columbia
and J. W. H. Monger, Geological Survey of Canada

General Geology

The Cascade Mountain System consists of an axial core of gneiss and granitic rock flanked on the east and the west by belts of folded and faulted, little-metamorphosed, strata of late Paleozoic to mid-Cretaceous age (Misch, 1966, McTaggart, 1970, Monger, 1970) (Figures A, 11:1). Northwards the axial core broadens and the Cascade System apparently merges with the predominantly granitic and high-grade metamorphic Coast Mountains.

The basic structural pattern results largely from intense deformation in mid-Cretaceous to Early Tertiary time, when four northwest-trending structural and lithological belts were formed. From east to west these belts are:—

(1) The Mesozoic belt seen on Day 10, separated from rocks to the east by the Pasayten fault, and highly deformed internally, with major folds overturned to the east and west-dipping thrust and reverse faults.

(2) The upper Paleozoic to lower Mesozoic belt, separated from rocks to the east by the Hozameen Fault, composed of chert, pelite, greenstone and limestone, and forming the Hozameen Group (Stop 11:1). These rocks are metamorphosed in the lowest greenschist to subgreenschist facies and are complexly folded and faulted and locally intruded by Cretaceous granitic plutons.

(3) The axial belt, separated from the belts to the east by a narrow zone along which movement has taken place, consisting of Mesozoic gneiss and schist and partly concordant Cretaceous quartz diorite (Stop 11:3). These rocks are over-

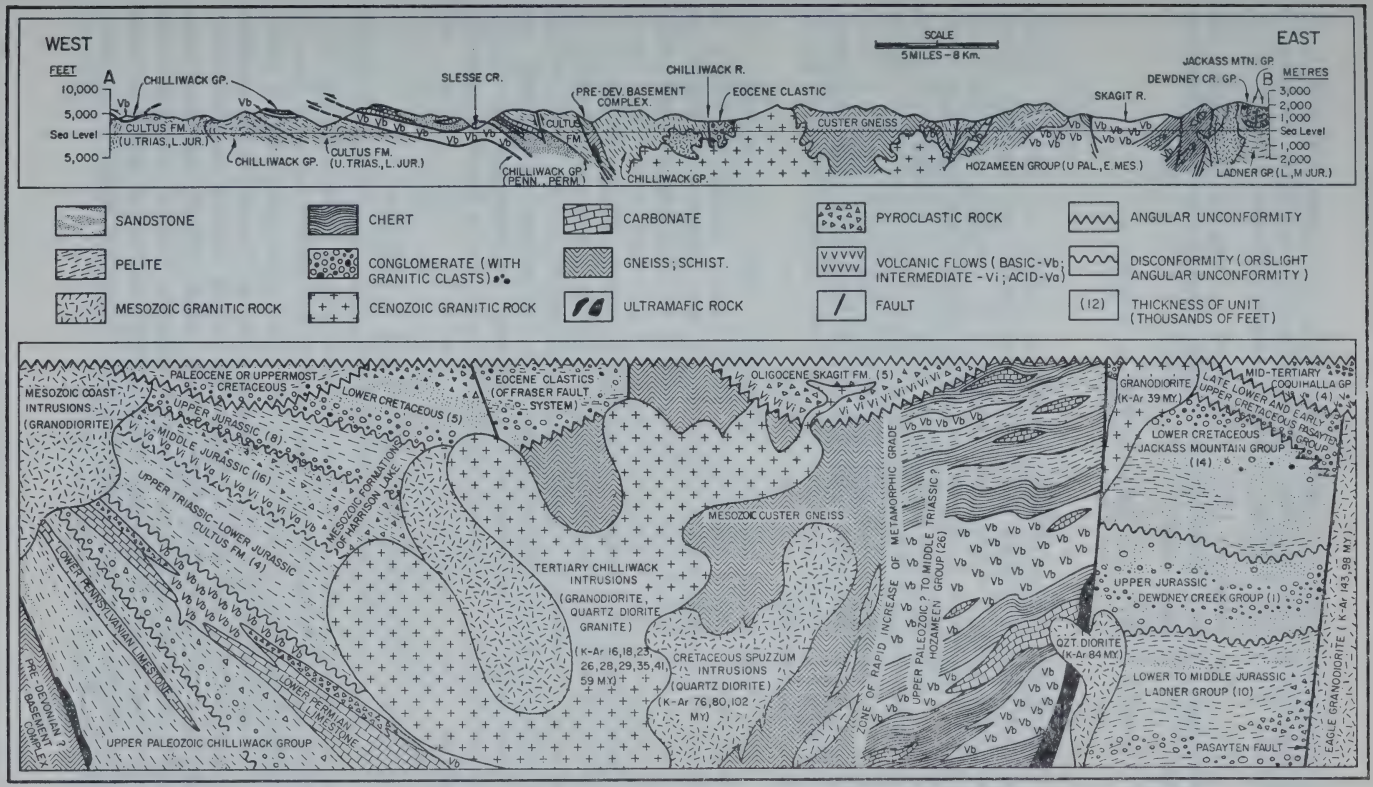


Fig. 11:1. Relationships and compositions of the rock units in the Cascade Mountains, with a cross-section.

lain unconformably by lower Tertiary conglomerate and sandstone (Stop 11:4) that accumulated in grabens, and were cut by discordant mid-Tertiary granodiorite.

(4) The western belt, composed of upper Paleozoic and Mesozoic strata that were folded, thrust and refolded in mid-Cretaceous to early Tertiary time (Stop 11:5).

These features are summarized in Figure 11:1.

Day 11

The Lower and Middle Jurassic strata of Skagit Bluffs Ladner Group (Stop 10:1) are succeeded across the Hozameen Fault to the west by ribbon chert, phyllite, altered basic volcanic rocks or greenstones, and limestone of the Hozameen Group. The Hozameen Fault is nearly vertical where crossed, lies partly along the Coquihalla Serpentine belt (an Alpine ultramafite some 37.5 miles (60 km) long and up to 2 miles (3 km) wide (Cairnes, 1930)) and is intruded at the highway by a small granitic pluton that has been dated at 84 m.y. (mid-Late Cretaceous) (Coates, 1970).

The Hozameen Group (Cairnes, 1944, McTaggart and Thompson, 1967), here about 19,000 feet (5800 m) thick, is disposed in northwesterly-striking folds. From the Hozameen Fault to the Hope Slide (Stop 11:1) the highway runs along the strike of the formations, most of the way in a valley excavated along and near a contact between thick greenstones and an overlying assemblage of ribbon cherts, all dipping to the southwest (*see* cross-section, Figure 11:1). The excursion passes recrystallized limestone at Twenty-mile Creek and ribbon chert is succeeded by massive greenstone at "Engineers's Road". The starting point for the day is at Pinewoods Lodge.

Stop 11:1 (Mile 32.5, Km 52.0) Hope Landslide

On January 9, 1965, some 130 million metric tons of greenstone rubble swept down the mountain side onto a valley floor composed of swamp, meadow, ancient landslide debris, fluvioglacial sand and gravel and a small lake. A mixture of slide-rock, mud and lake water was driven up the opposite (southwest) slope; some flowed back and came to rest on the valley floor against the lower slopes of the slide; much was deflected northwestward and rushed more than 3 miles (5 km) down valley as a mud-flow and some was deposited to the southeast as a 45 feet (14 m) thick apron, thinning in that direction (Mathews and McTaggart, 1969).

Two earthquakes about 3 hours apart and of magnitudes 3.2 and 3.1, the epicentres of which are placed within a mile of the slide, occurred at the time of the slide.

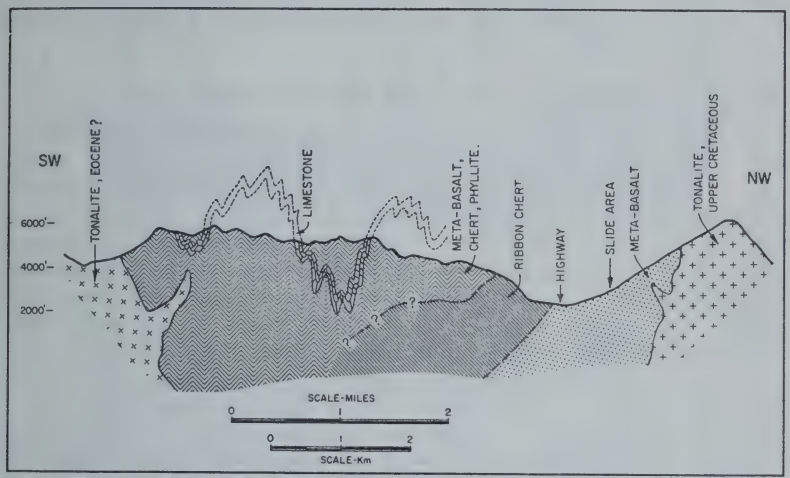


Fig. 11:2. Cross-section at Hope Landslide, showing formations of the Hozameen Group and structural relations.

The slide surface consists of metabasalts, striking parallel with the valley and dipping 45 to 60 degrees southwest (Figure 11:2). These rocks are massive flows, obscurely layered but strongly jointed and locally faulted. The volcanic succession is overlain by ribbon chert which is well exposed along the southwest wall of the valley, about 330 feet (100 m) from the parking area. Volcanic rocks and chert, both of the Hozameen Group, are intruded by buff-coloured felsitic sheets and irregular bodies that are easily visible on the slide surface. Many of these dip about 30 degrees southwest.

It is reasonable to suppose that the slide was triggered by the earthquakes. The surface along which the slide occurred seems not to be an original flow contact, for although primary volcanic features are very obscure in the slide area, the general attitude of the rocks is steeper than the slide surface. It is possible that the somewhat irregular slide surface follows or is controlled by a combination of the contacts between felsite sheets and greenstone, gently dipping stretches of flow contacts, and unrecognized slip or fault surfaces of appropriate attitude.

From Stop 11:1 the excursion continues westward in Hozameen rocks and, at 6.9 miles (11 km) before Hope, proceeds past tonalite of mid-Tertiary age. The excursion crosses the Fraser River at Hope over a bridge whose western abutment is on Eocene conglomerate. Road cuts in Eocene conglomerate are in a segment of the old highway 0.6 miles (1 km) beyond the bridge.

Stop 11:2 (Mile 46.2, Km 73.9) Eocene clastic rocks

At Stop 11:2, Eocene conglomerates and arenite dip vertically. The conglomerate contains boulders of gneiss, chert, lava, diorite, tonalite, quartz monzonite, sandstone, etc., many of which are obviously derived from neighbouring rock units. Arkosic layers, with poorly preserved leaves and stems contain pollen grains indicating an Eocene age. The beds overlie unconformably a tract 3.5 square miles (9 km^2) of upper Paleozoic (?) highly deformed meta-volcanic rock, pelite and limestone largely surrounded and isolated by granitic rock (Figure 11:3). The basal unconformity lies in a gully about 650 feet (200 m) to the east. Here and at Fraser River it is vertical, but farther south the dip is gentle. Eocene beds continue to the west about 1950 feet (600 m) where they are in contact with Upper Cretaceous diorite (Spuzzum intrusions) along the Hope Fault. To the south, Eocene beds are intruded by Oligocene and Miocene members of the Chilliwack batholithic complex (Richards and White, 1970). The Hope Fault (Read 1960), and the Yale Fault which lies along the east side of the Fraser River, are the main faults of the Fraser fault zone which extends northwards from Washington State, with interruptions, for 155 miles (250 km). Over much of its length the zone is made up of two main sub-parallel faults joined by many cross-faults, with branches extending to the northwest. For long stretches, this pair of bounding faults seems to form a graben in which Eocene beds accumulated. In many places serpentinized peridotite has been emplaced along or near the faults. Right-lateral movement is suggested by deflections in structures near this zone but such movement did not persist after emplacement of the Upper Cretaceous diorite (Spuzzum intrusions) of the next stop. There has been little or no post-Miocene movement on the zone south of Hope, where Oligocene-Miocene plutons intrude it, but are not faulted.

From Stop 11:2 the excursion continues north along the Fraser fault-zone across the sub-Eocene unconformity (covered) into underlying deformed argillite (exposures on highway

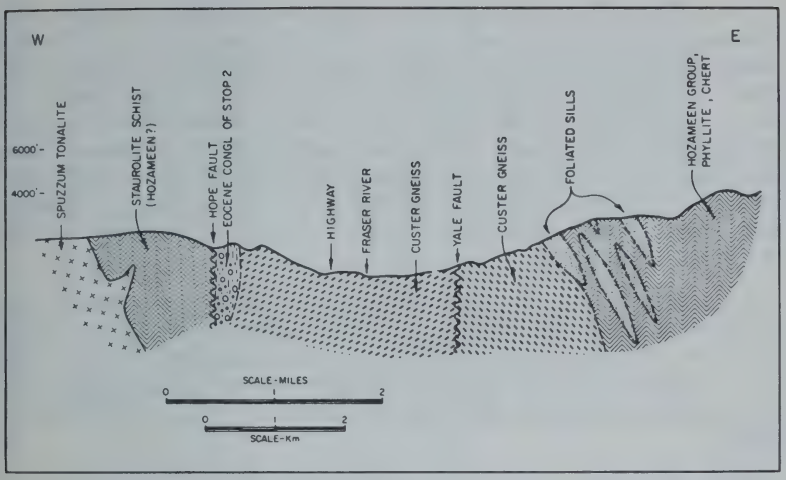


Fig. 11:3. Cross-section of Fraser River, 2 miles north of Stop 11:2.

at small lake and beyond) and across a concealed contact (fault?) into white-weathering Custer gneiss (McTaggart and Thompson, 1967), named Skagit gneiss in northern Washington (Misch, 1966, 1968). Much of the Custer gneiss is layered, feldspathic and migmatitic, resembling the Shuswap gneiss of south central British Columbia. It contains a few layers of marble, kyanite-staurolite schist, amphibolite, and much mylonite. Hozameen beds, with increasing metamorphism and shearing, seem locally to grade into Custer gneiss. Similar gneiss is structurally conformable and, in some places, gradational into Upper Cretaceous tonalite. Uranium-lead studies of zircon and sphene in Skagit gneiss from northern Washington (Mattinson, 1970) suggest that zircon crystallized 1.6×10^9 years ago, and that the rocks were metamorphosed and migmatized in Late Cretaceous time. Gneiss between Haig and Yale is highly faulted and fractured and joints are coated with laumontite. Near Yale and north, the gneisses are intruded by tonalite and diorite, locally highly sheared.

Stop 11:3 (Mile 71.5, Km 114.4) Custer gneiss, near Alexandra Bridge

From the bridge there is a view of the Fraser Canyon, developed along the north-trending Fraser fault zone. In the road cut just west of the bridge foliated Upper Cretaceous tonalite is exposed and contains conformable xenoliths of Custer gneiss hundreds of feet wide.

From Stop 11:3, the excursion returns to Hope and proceeds westward along the south side of the Fraser River. The flat valley floor is underlain by unconsolidated gravels, sands and clays of glacial and fluvioglacial origin and talus accumulations (Armstrong et al, 1965). In places these deposits reach considerable thicknesses, such as near Chilliwack where there are 1,800 feet (550 m) of unconsolidated material in the valley bottom. The excursion leaves the highway at the Chilliwack exit, turns south and then east at Vedder Crossing up the Chilliwack Valley.

This valley cuts across pre-Devonian (?) greenstone near Vedder Crossing bridge and a small outcrop of Upper Cretaceous or Paleocene feldspathic sandstone about ¼ mile (400 m) to the west. The route continues up the valley to the flat above and east of the junction of Slesse Creek and Chilliwack River.

Stop 11:4 (Mile 142, Km 227) Structures on west side of Cascade Mountains, Chilliwack Valley.

Some of the westerly-directed overturned folds and thrusts on the west side of the Cascade Mountains are visible from this locality (Figure 11:4). These structures are developed in Pennsylvanian and Permian clastic rocks, limestone and volcanic rocks of the Chilliwack Formation and Upper Triassic and Jurassic pelite, siltstone and sandstone of the Cultus Formation.

From this locality the excursion rejoins the highway at Chilliwack entry and proceeds west to Vancouver. The mountains to the north are mainly granitic rocks of the Coast Mountains, and the Cascade Mountains to the southwest are dominated by the Quaternary volcanic cone of Mount Baker. The Fraser Lowland is a structurally low area that is part of the Georgia Depression. This has been the site of molasse-type deposition since the late Cretaceous. The north and east sides of this basin are rimmed by Tertiary sandstone, some of which may be seen dipping gently to the west, on the west end of Sumas Mountain. Sedimentation in the modern Fraser delta is merely the continuation of this process.

Vancouver is built upon these Tertiary strata, Tertiary basaltic plugs, and on Pleistocene gravels and sands. North and West Vancouver are underlain in part by granitic rock that is the southermost extremity of the Coast Range.

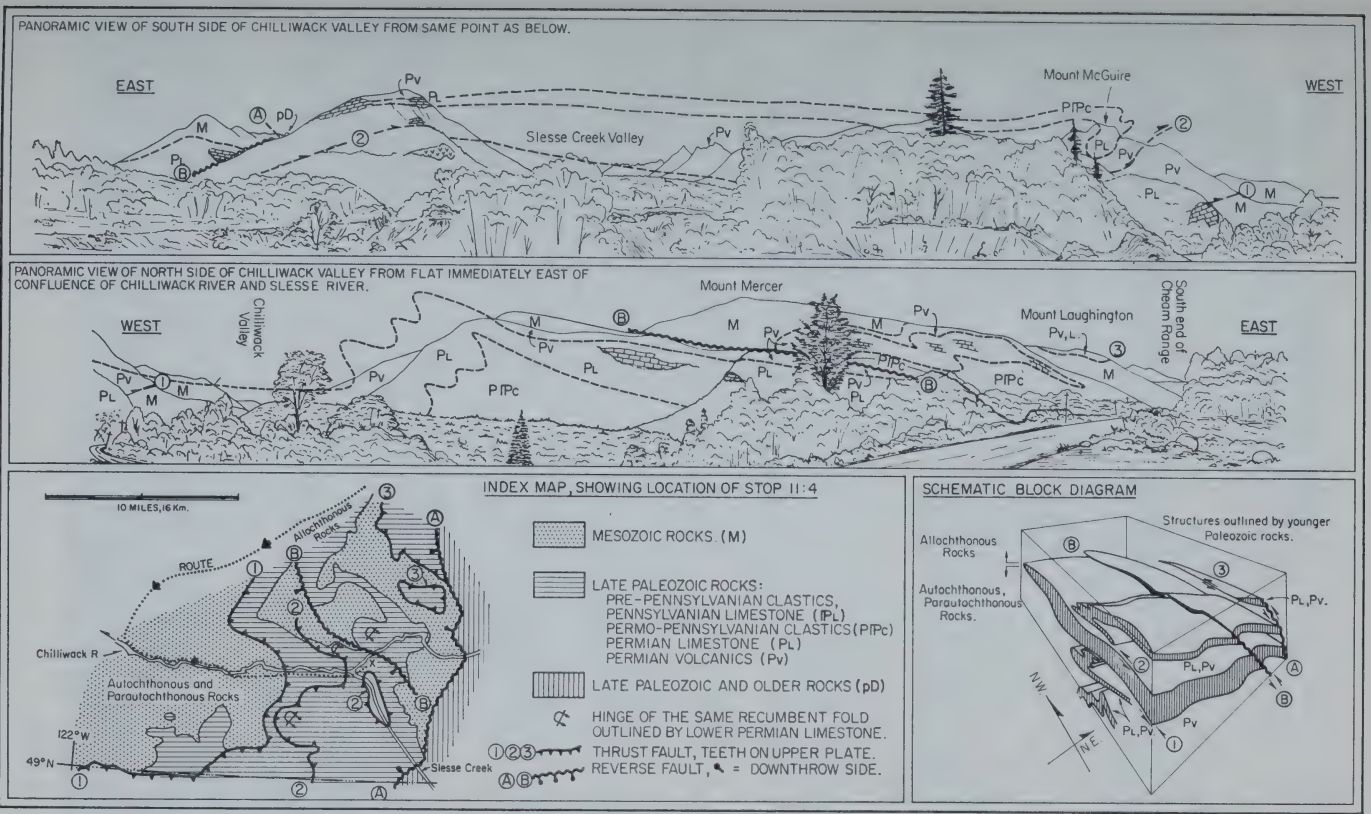


Fig. 11:4. Structures in the Chilliwack Valley, west side Cascade Mountains.

Coast Mountains

by K. C. McTaggart, University of British Columbia

General Geology

The Coast Mountains are about 1120 miles (1800 km) long and 100 miles (160 km) wide and extend from Vancouver to the Yukon and Alaska.

The Coast Mountains are a strongly dissected, rugged terrain cut by deep glacial valleys and fiords, with relief of many hundreds, even thousands, of feet. The mountains reach a maximum elevation of 13,260 feet (4,050 m), 190 miles (300 km) northwest of Vancouver. Snow fields and glaciers cover many areas above 6500 feet (2000 m) in elevation.

The Coast Mountains are underlain by granitic rocks overlain by, or enclosing tracts of, metamorphic rocks (Hutchison, 1970). In early accounts of the Coast Mountains, reference was made to the "Coast Range Batholith", which implied that the area is underlain by a single huge batholith, but this is a misconception. The tract nowadays referred to as the "Coast Range Batholithic complex" or the "Coast Crystalline complex", is made up of scores, perhaps hundreds, of "granitic" plutons of both mesozonal and epizonal types, of many compositions but mostly tonalite and of ages ranging from Jurassic (or older) to Eocene (or younger) (Roddick, 1966). Some plutons were apparently emplaced metasomatically. Some were emplaced as highly fluid magmas, or as mixtures of crystal and liquid, making room by a variety of mechanisms. Most of the metamorphic rocks within the crystalline complex are foliates, ranging in grade up to that of sillimanite gneiss. Such rocks occur as screens, or as roof pendants, some of them scores of miles long. Relatively young unmetamorphosed sedimentary rocks lie against the flanks of the complex and very late Cenozoic volcanoes pierce the complex, as, for example, in Garibaldi Park, (Mathews, 1958) north of Vancouver.

Day 12

The route crosses Lions Gate Bridge from Vancouver into West Vancouver and parallels the shore-line. For much of the distance it is over granitic rocks. Mile 0 is at the intersection of Taylor Way and Marine Drive. From this locality continue west on Marine Drive.

Stop 12:1 (Mile 5.3, Km 8.5) Marine Research Station, near Cypress Creek, West Vancouver. Granitic rocks and dykes of the Coast Mountains.

Biotite-hornblende granodiorite, a common rock type of the Coast crystalline complex (Roddick, 1965) is cut by dykes of aplite, pegmatite, and porphyritic andesite. This granodiorite contains many dark roundish inclusions and a peculiar layered zone (upper exposures) that vaguely resembles well-developed rhythmic layering found in diorite to the north. Some andesite dykes are multiple, and central parts were emplaced later than the marginal parts (Ahlborn, 1971).

The dykes are unusually irregular and discontinuous. Many of their structural features can be explained by assuming intrusion of andesite magma into regular openings controlled by fracturing in several directions, with local terminations. Some interruptions of the dykes, however, seem to be due to disruption after emplacement and suggest that the granodiorite into which the dykes were emplaced was still capable of plastic deformation at the time of their emplacement. In this respect, they resemble synplutonic dykes described by Roddick and Armstrong (1959) (see next stop).

Stop 12:2 (Mile 5.7, Km 9.1) Caulfeild Cove, Granitic rocks and gneiss of the Coast Mountains.

At Caulfeild Cove, typical granodiorite of the Coast Range is in contact with the Caulfeild gneiss (Phemister, 1945), mainly amphibolite, that is part of a roof pendant, screen, or raft, 1,000 feet (300 m) long. The gneiss is considered to be pre-Jurassic (Roddick, 1965). Potassium-argon dates of 95 and 99 m.y. (Baadsgaard et al, 1961) suggest the granodiorite to be mid-Cretaceous.

Dark amphibolites, layered and streaky, consist of plagioclase (An_{58}) and hornblende. Light-coloured layers are largely plagioclase (An_{42}), with minor quartz and K-spar. Phemister considered these rocks to have been originally mafic lavas, tuffs and breccias.

The amphibolite is cut by dykes of granodiorite, by irregular masses and dykes of pegmatite, partly with graphic texture, by two generations of aplite, and by two groups of andesite dykes. One type of andesite is weakly foliated, relatively older and termed "pre-batholithic" by Phemister; the other younger, unaltered, is probably Cenozoic.

Phemister (1945) mapped the area in detail and, undoubtedly influenced by granodiorite dykes showing dilation offset

and rotated slabby xenoliths, concluded that the granodiorite in the vicinity was emplaced magmatically. He pointed out, however, that remnants of certain "pre-batholithic dykes", now enclosed in the granodiorite just north of Caulfeild, retain their original orientations, a feature, he noted, more compatible with granitization than with magmatic emplacement. H. H. Read (*in* Phemister, 1945, discussion) disagreed with Phemister's interpretation, and argued that the evidence favoured granitization. Roddick (1965) and Armstrong (1968), having examined a large area in the vicinity of Vancouver, concluded that the batholithic rocks were formed by granitization but conceded local magmatic action. They re-interpreted the "pre-batholithic" dykes as "synplutonic" dykes, arguing that they were emplaced during the plutonism, that is, during the formation of the granitic rocks.

From this locality, a brief excursion is made up the fiord of Howe Sound, returning to the ferry at Horseshoe Bay.

The Insular Belt

by J. E. Muller, Geological Survey of Canada

General Geology

The Insular Belt embraces Vancouver Island and the Queen Charlotte Islands together with surrounding oceanward and landward shelf-areas, the latter including Georgia Strait with the Gulf Islands and Queen Charlotte Sound. Vancouver Island consists of a mountainous core, up to 7095 feet (2160 m) in elevation, of volcanic, plutonic and sedimentary rocks. Westward toward the Pacific Ocean the mountains open up in a fiord-coast, less deeply indented than the mainland Coast Mountains; eastward toward the Strait of Georgia they descend to the Nanaimo Lowlands. Figure 12:1 shows the main formations, and their relationships (*see* Clapp and Cooke, 1917, Muller and Carson, 1969, Jeletzky, 1970).

Three successive cycles of basic to intermediate volcanism, coupled with more or less intensive plutonism and succeeded by uplift, erosion and clastic sedimentation, can be distinguished. The first cycle is composed of Carboniferous sediments (units 3 and 4 on Figure 12:1), and mid-Paleozoic basic to intermediate volcanic rocks which are partly metamorphosed and dioritized (units 1, 2). The second cycle contains Triassic basic volcanics (unit 5), up to 19,000 feet (6,000 m) and Lower Jurassic intermediate volcanics (unit 8) up to

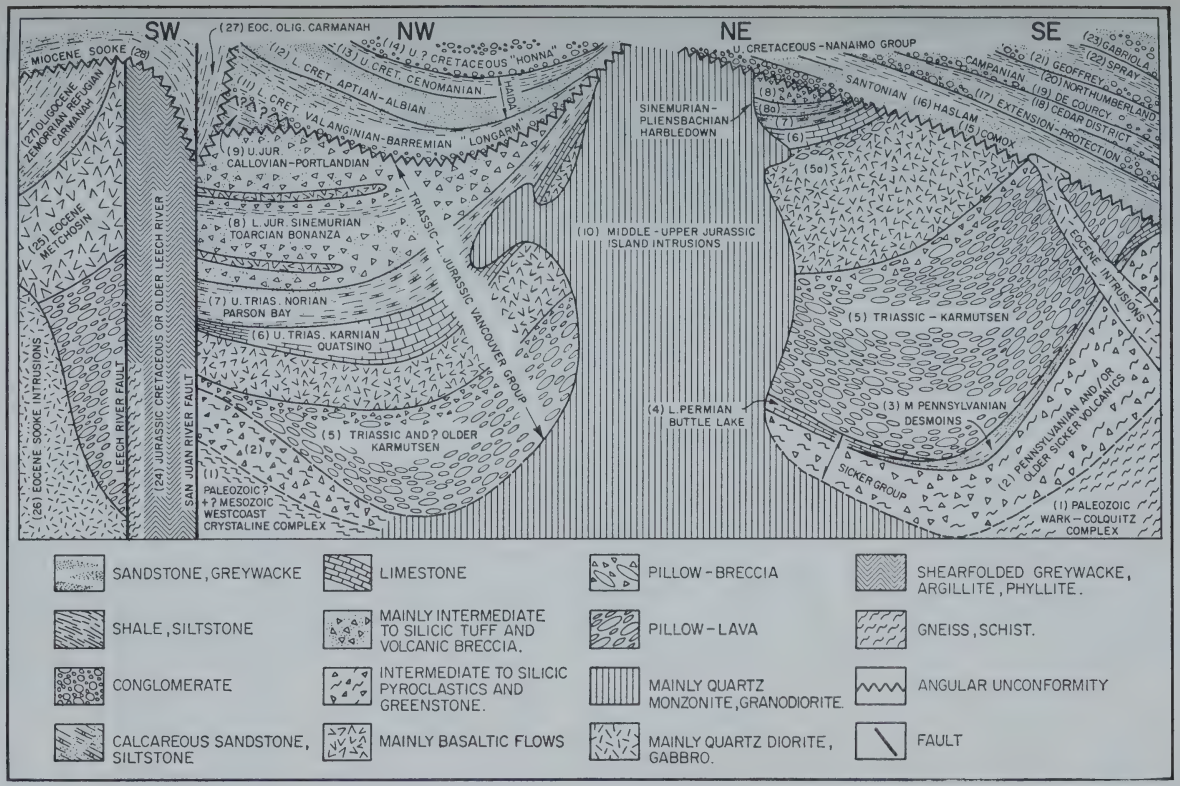


Fig. 12:1. Relationships of formations on Vancouver Island and Gulf Islands. Reference numbers of formations shown in brackets.

6,000 feet (1830 m) thick. These are separated by Upper Triassic (units 6, 7) and Lower Jurassic (unit 8a) sedimentary rocks that are up to 5,000 feet (1525 m) thick. This cycle is terminated by Middle to Upper Jurassic intrusions (unit 10) yielding potassium-argon ages from 142 to 181 million years. It is disconformably overlain by a mainly Lower Cretaceous clastic wedge (units 11-14) that is up to 6,000 feet (1830 m) thick on the west side and an Upper Cretaceous clastic sequence (units 15-23) that is up to 9,000 feet (2745 m) thick on the east side of the island. The third cycle comprises Eocene basaltic flows, pillow lavas and gabbroic plutons. Two major faults, the San Juan River Fault and the Leech River Fault, separate the rocks of this cycle, which outcrop only on southern Vancouver Island and on the Olympic Peninsula to the south, from rocks of the first two volcanic-plutonic cycles, which underlie the rest of Vancouver Island.

The structure of the Insular Belt is dominated by fracturing, block-faulting and tilting of strata, the natural response of a competent volcanic-plutonic shield to tectonic forces. Local folding of bedded strata is generally confined to fault-zones and plutonic contact-zones. Northwesterly strike-faults and northeasterly cross-faults affect Upper Cretaceous strata but some of the faulting may be older.

Economic deposits are varied and relatively abundant. They include Cu-Zn-Pb-Au-Ag-bearing massive sulphides in massive Paleozoic volcanics, Fe-Cu-bearing skarns in Triassic carbonates at contacts with Jurassic intrusions, "porphyry" Cu-Mo deposits related to either Jurassic or Tertiary plutons and Au-Ag vein deposits marginal to Tertiary plutons. Coal produced from Upper Cretaceous sediments was for many decades the main mineral product of Vancouver Island (Muller and Carson, 1969).

The Vancouver Island part of the excursion begins with the crossing of Georgia Strait via B. C. Government ferry from Horseshoe Bay to Nanaimo. The Georgia Depression separates the Coast Range and Insular Belts. On its eastern side and north of the ferry-route Texada and Lasqueti Islands are underlain mainly by Triassic volcanics and sediments (units 5, 6), and adjacent to Vancouver Island north and south of the ferry-route are islands underlain by Upper Cretaceous strata (units 15-23). The Strait is probably in part a graben-like structure, with northwesterly trending normal faults separating northeasterly dipping blocks on the west side. Subcrops are mainly Cretaceous, Tertiary and Pleistocene strata.

The highway from the ferry-landing at Departure Bay, Nanaimo, passes through Parksville and Courtenay to Campbell River, following the Island coast through the "Nanaimo Lowlands". These are underlain by the Nanaimo and Comox Basins of Upper Cretaceous coal-bearing sediments, separated by a ridge of Carboniferous to Triassic rocks.

Stop 12:3 (Mile 32.0, Km 51.5 from the Nanaimo ferry-dock) Little Qualicum Falls Park. Uncomformity between Upper Cretaceous and older rocks.

The river has cut a small canyon through granitic rocks (unit 10) which, near the parking lot, are hybrid in character due to proximity of the contact with Triassic volcanics (unit 5); however a short distance downstream they are "clean" granitic rocks. The sub-Cretaceous unconformity is remarkably uneven; vertical clefts in the granite several meters deep are partly filled with boulder-conglomerate derived mainly from the granite. Nearby, marine shale is exposed that yielded *Inoceramus naumanni*, indicative of the Late Cretaceous (late Santonian) age of these rocks (Muller and Jeletzky, 1970). The beds are the top part of the lowest depositional cycle of the Nanaimo Group (Figure 12:1). Depositional cycles of the Nanaimo Group are generally transgressive, starting with fluvio-deltaic conglomerate, sandstone and lagoonal shale-coal deposits, grading upward into near-shore shale-sandstone sequences and off-shore thin-bedded silt-shale turbidites. Of the four or five recognized cycles the first one yielded coal in Comox Basin and the second one in Nanaimo Basin. Interestingly, the conglomerate-sandstone phase of the first depositional cycle (unit 15) is missing here and marine shale (unit 16) almost directly overlies the unconformity.

The remainder of the excursion to Campbell River leads along the coast through the Comox coal-basin, where coal was mined from several seams in the Comox Formation (unit 15). The route passes Union Bay with remains of coal-loading docks. To the east, Denman and Hornby Islands are underlain by Campanian to Maestrichtian rocks of later depositional cycles (units 18-23). To the west the Beaufort Range consists of Triassic volcanics (unit 5) unconformably underlying, but partly in fault contact with the Cretaceous beds. Total distance from Nanaimo 108.0 miles, 173.8 km.

Day 13

The emphasis in Day 13 is on the Carboniferous to Triassic volcanic-sedimentary succession exposed along Buttle Lake

(Figure 13:1). The day begins with a non-stop drive to the south end of the lake.

Stop 13:1 (Mile 52, Km 83.7) Upper Paleozoic volcanic rocks at the south end of Buttle Lake

Road cuts show pre-Middle Pennsylvanian (unit 2 on Figure 12:1) fine-grained banded tuff, coarse-grained tuff and volcanic breccia with fragments up to 4 inches (10 cm) across. The fragments are amygdaloidal epidotized lava and tuff. Thin sections show fragments of feldspar, dacitic lava, some free quartz and recrystallized glass-globules. The rocks contain chlorite and prehnite, and are in many places converted to greenschist. These volcanics may be considered as the upper part of the first volcanic cycle. The Cu-Zn-Pb-Ag-Au sulphide deposit of Western Mines, west of Buttle Lake, is within tuff and schist of this formation. The excursion returns northward along outcrops of similar volcanics with diabase intrusive into them.

Stop 13:2 (Mile 59.2, Km 95.2) Upper Paleozoic limestone, Buttle Lake

Recrystallized crinoidal limestone (unit 4) is exposed in road-cuts. R. W. Yole (1963) collected probable Lower Permian fossils in an equivalent carbonate unit in the mountains west of Buttle Lake. The limestone overlies greywacke and argillite (unit 3) not exposed along the road; the latter in turn overlie the volcanics of Stop 1. The view of the mountains on the west side of Buttle Lake shows the north-dipping sequence of Paleozoic volcanics, Permian limestone and Triassic volcanics. Offsets of the limestone along normal faults are visible.

Northward the route passes some red beds and minor ribbon-cherts that constitute the basal part of the Triassic-Jurassic volcanic cycle. Basal conglomerates are not seen here, although they are present in other places.

Stop 13:3 (Mile 66.4, Km 106.9) Upper Triassic volcanics, Buttle Lake

The red beds and cherts are directly overlain by tholeiitic pillow lavas, which at Buttle Lake are some 13,000 feet (4,000 m) thick. Here the pillows are closely packed, ball-to ellipsoid-shaped, and 8 inches (20 cm) to 3.2 feet (1 m) across. Chilled rims are visible in places. Nests of quartz and epidote in many places fill the triangular spaces beween pillows. Thin sections show diabasic plagioclase-pyroxene-opaque mineral assemblages. Megascopic or microscopic clusters of feldspar

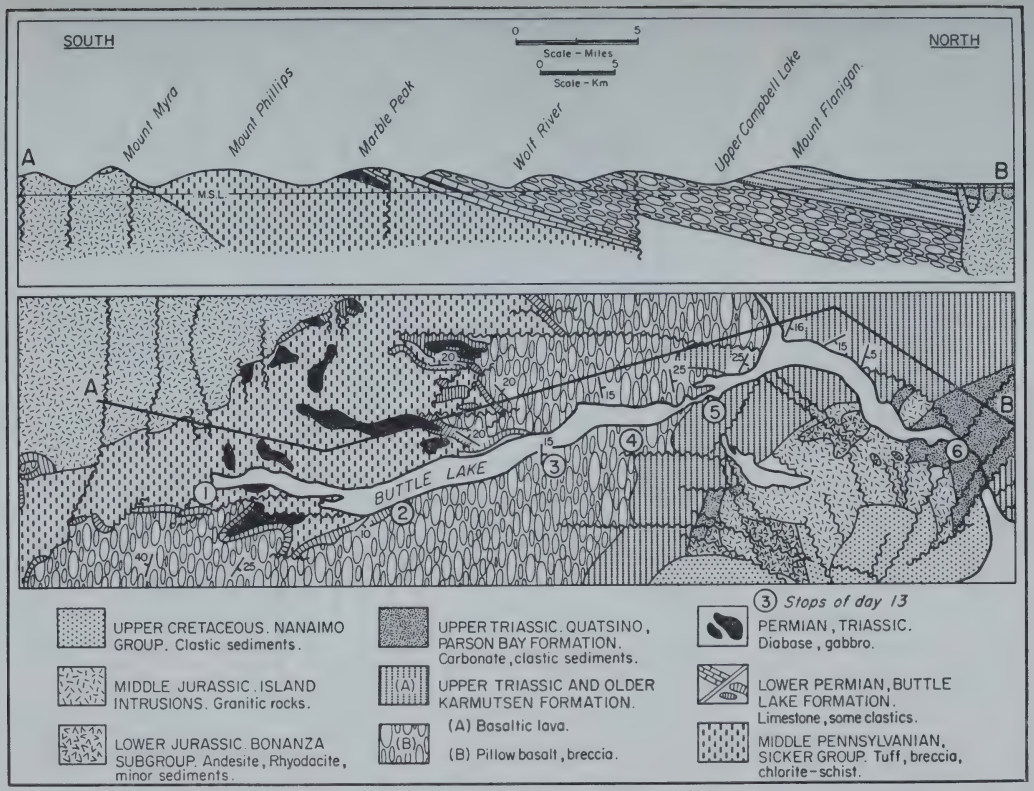


Fig. 13:1. Paleozoic-Mesozoic sequence, Buttle Lake, Vancouver Island.

are common. The pillow-lavas are submarine, and possibly were sub-oceanic effusions forming large basaltic shield volcanoes.

Stop 13:4 (Mile 71.3, Km 114.7) Upper Triassic volcanics, Buttle Lake

The outcrop consists of aquagene tuff that together with pillow-breccias commonly overlies the pillow lavas. The tuff consists of globules, granules, shards and basaltic fragments (visible with hand-lens); the breccias contain in addition, larger fragments of pillows. They were described by Carlisle (1963) who considers them to have formed in turbulent water. Thus aquagene tuff may indicate rising of the volcanic ridge to shallow depths.

Stop 13.5 (Mile 74.0, Km 119.1) Upper Triassic volcanics, Buttle Lake

The outcrop shows the second major type of Triassic volcanic rock — massive basalt flows, in this outcrop 1.6 feet (50 cm) to several feet thick but elsewhere commonly 15 to 100 feet (5 to 30 m) thick. The flows are generally amygdaloidal at top and bottom, with vesicles filled mainly by quartz, epidote or pumpellyite. The physical conditions responsible for the change from pillowed to bedded lava without appreciable change are not well known. Bedded lava may be due to more rapid extrusion, to greater volatile-content, or perhaps to a change from submarine to subaereal environment. The upper part of the Triassic volcanic pile contains a thin sedimentary layer with Karnian fossils, overlain by another 1,000 feet (300 m) sequence of pillow-lavas, followed by bedded lavas (unit 5a), not exposed at road-level. The excursion next passes by hornblende-quartz diorite and granodiorite, intrusive into the basalt. The Triassic basalt is overlain by Karnian massive limestone and Norian black thin-bedded calcareous siltstone and shale. These formations are preferentially invaded by sills, dykes and laccoliths of granitic Island Intrusions (Figure 12:1; unit 10, into unit 6, and 7) with resulting Cu-Fe skarn deposits. The exhausted Argonaut iron-mine is just east of the excursion route. The route passes a small exposure of silicified Triassic limestone (unit 6) and road-cuts in Jurassic dacite porphyry.

Stop 13:6 (Mile 86.7, Km 139.5) Triassic sedimentary rocks, spillway of dam

The spillway north of the power dam exhibits mainly porphyry intruded into Triassic sedimentary rocks with only

minor blocks of thin-bedded black siltstone with *Monotis subcircularis* Gabb (unit 7) "floating" in the porphyry. The cut also affords a small-scale model of the fault-tectonics of the Island. The maze of near-vertical faults is not due to a specific fault-zone but rather is the reaction of rock of medium competency to the stress-field that existed throughout the region. Some faults are tensional and contain dykes that mainly trend northeast. One set of faults trending 130° shows northeast downthrow of the *Monotis*-bearing-beds. Another set is approximately at right angles to these and offsets them.

From this stop the excursion returns to Nanaimo by the route already traversed (total day's distance 205 miles, 329.9 km).

Day 14

The last day of the excursion is concerned with the Upper Cretaceous sedimentary rock, Paleozoic ribbon-chert, the metamorphic "basement" of Vancouver Island (unit 1) and Tertiary and (?) Mesozoic rocks south of two fundamental faults. (Figure 12:1, units 24-28). The excursion begins at the Malaspina Hotel in downtown Nanaimo.

Stop 14:1 (Mile 4.8, Km 7.7) Upper Cretaceous sedimentary strata, Harmac

The cut on the road to Harmac near Nanaimo River shows Upper Cretaceous (unit 17) medium-grained sandstone with one coal-seamlet in the Campanian (Extension-Protection) of the second depositional cycle. The Extension-Protection was the productive formation in the Nanaimo Basin. The sandstone consists of sharply angular even-sized grains of quartz, plagioclase and biotite in a carbonate matrix, which was apparently freshly derived from granitic terrane. Farther west the gradation from deltaic sandstone to marine shale (Cedar District, unit 18) is poorly exposed. The Island Highway from Nanaimo to Duncan traverses alternately Cretaceous sediments (units 16-18) and underlying Paleozoic volcanics (unit 2) or Mesozoic granodiorite. The older and younger rocks are juxtaposed by northeast- and northwest-trending faults.

Stop 14:2 (Mile 50.8, Km 81.7) Altered granodiorite, Malahat Lookout

If the weather is clear the lookout affords a splendid view of Saanich Peninsula, the Canadian Gulf Islands, the American San Juan Islands and the Quaternary Mount Baker volcanic cone. The exposed rock is highly altered granodiorite.

Stop 14:3 (Mile 57.3, Km 92.2) Ribbon cherts

The hill beside Malahat Drive supporting a powerline-tower affords a magnificent exposure of ribbon-cherts. The beds of black to greenish grey, whitish-weathering chert are 0.5 - 1.5 inches (1 - 4 cm) thick, separated by films of graphitic matter. Thin sections show them to be silicic tuffs consisting apparently of fine dust of quartz, feldspar and (?) hornblende. These rocks are uncommon on Vancouver Island but are widespread on the adjacent San Juan Islands. There, associated limestones locally contain Permian (Guadalupian) fusulinids according to W. R. Danner (1966). Dragfolds in the beds are believed to be soft-sediment slump-folds.

Stop 14:4 (Mile 60.8, Km 97.8) Upper Paleozoic-Mesozoic (?) schist, Leech River Schist

Leech River "schist" (unit 24) is a greywacke-pelite sequence of either upper Paleozoic or Jurassic-Cretaceous age. On the west coast of Vancouver Island it is overlain unconformably by Miocene sediments. This sequence has been isoclinally folded and is locally metamorphosed to the biotite grade of regional metamorphism. It forms a block between two major reverse faults, the San Juan River Fault to the north and the Leech River Fault to the south, separating the Paleozoic-Mesozoic geological province of the main part of Vancouver Island from the Tertiary geological province that outcrops chiefly on the Olympic Peninsula south of the Strait of Juan de Fuca. The Leech River Fault is marked by a strong northward decrease in regional gravity.

At stop 4 the Leech River schist consists of low-grade phyllitic slate interbedded with light-green phyllitic greywacke. The bedding is sub-parallel with a well-developed near-vertical slaty cleavage at azimuth 300. The cleavage shows kink-bands and also slickensides dipping 50° southeast on the cleavage planes, perhaps indicative of oblique movement on the adjacent Leech River Fault which separates these rocks from Eocene basalts to the south.

Stop 14:5 (Mile 76.9, Km 123.7) Eocene basalts and sediments

If tides permit, Stop 5 at Albert Head on Juan de Fuca Strait will show Eocene basalts (Metchosin, unit 25) which look very similar to the Triassic volcanics seen on Day 13. These rocks are pillow-lavas, flow-lavas and minor bedded tuff, grewacke and limestone. The sediments contain in a few places *Turritella* and orbitoid foraminifera, probably *Discocyclina* according to B. E. B. Cameron (pers. comm.), indicating

Middle Eocene age. From this locality to Victoria the excursion leads past Tertiary, Paleozoic and Mesozoic (?) volcanic, granitoid and gneiss rocks.

Stop 14:6 (Mile 90.4, Km 145.5) Gneiss at Cattle Point

At this locality is a large exposure of "Colquitz quartz-diorite-gneiss", which has a hornblende quartz diorite composition, and is fine- to medium-grained with a consistent near-vertical foliation at azimuth 340. The gneiss represents the Paleozoic basement complex (unit 1) and possibly is the recrystallized equivalent of Paleozoic volcanic rocks (unit 2) As at Stop 13:6, the large outcrop is an example of the complex faulting pattern common on Vancouver Island and shows several north-trending faults, accompanied by steeply-plunging folds, and offset by northeasterly-trending faults. Total day's distance about 95 miles (153 km).

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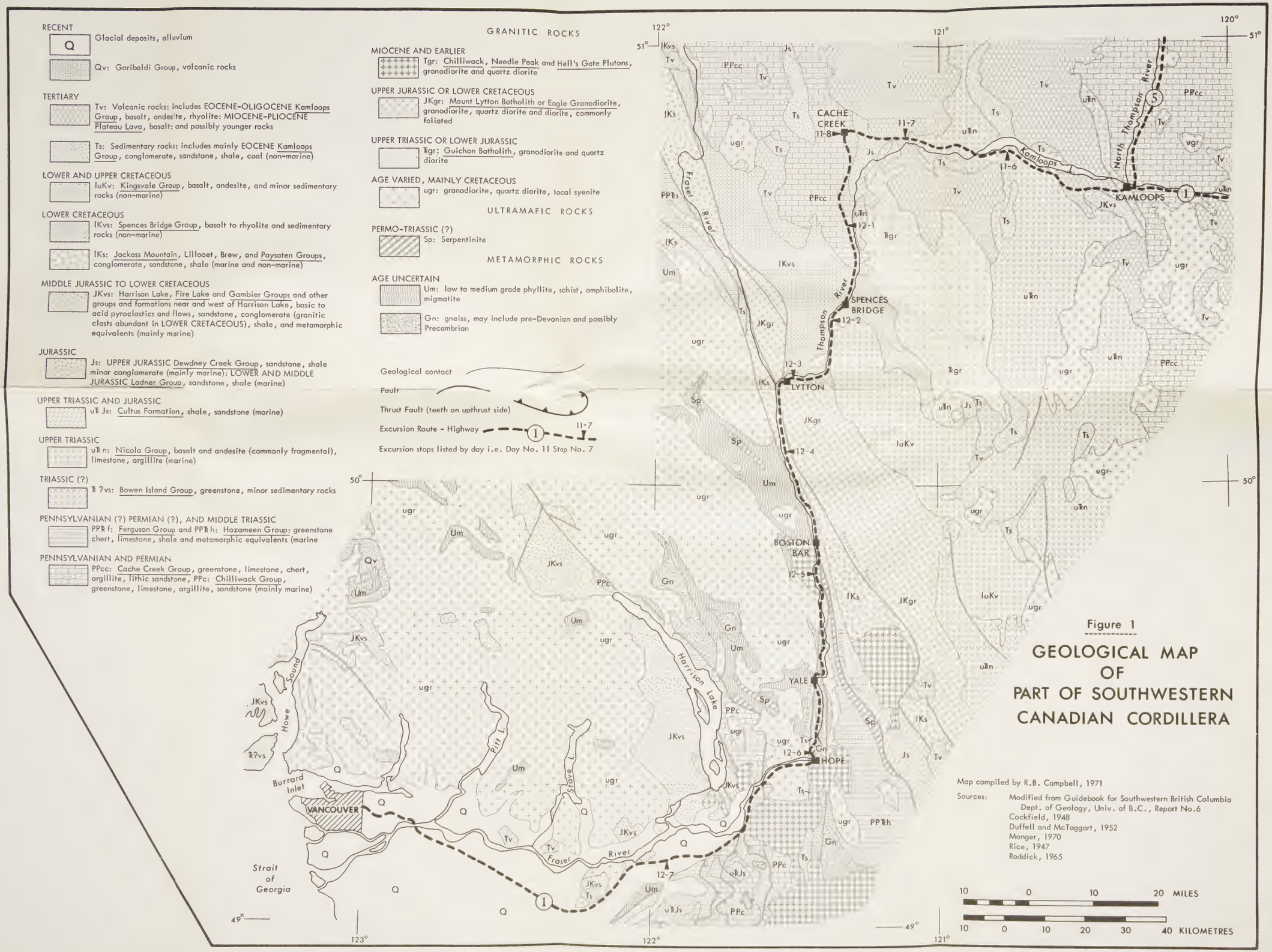

RECENT
Q
Glacial deposits, alluvium
Qv: Garibaldi Group, volcanic rocks
TERTIARY
Tv: Volcanic rocks: includes EOCENE-OLIGOCENE Kamloops Group, basalt, andesite, rhyolite: MIOCENE-PLIOCENE Plateau Lava, basalt: and possibly younger rocks
Ts: Sedimentary rocks: includes mainly EOCENE Kamloops Group, conglomerate, sandstone, shale, coal (non-marine)
LOWER AND UPPER CRETACEOUS
luKv: Kingsvale Group, basalt, andesite, and minor sedimentary rocks (non-marine)
LOWER CRETACEOUS
lKvs: Spences Bridge Group, basalt to rhyolite and sedimentary rocks (non-marine)
lKs: Jackass Mountain, Lillooet, Brew, and Paysaten Groups, conglomerate, sandstone, shale (marine and non-marine)
MIDDLE JURASSIC TO LOWER CRETACEOUS
JKvs: Harrison Lake, Fire Lake and Gambier Groups and other groups and formations near and west of Harrison Lake, basic to acid pyroclastics and flows, sandstone, conglomerate (granitic clasts abundant in LOWER CRETACEOUS), shale, and metamorphic equivalents (mainly marine)
JURASSIC
Js: UPPER JURASSIC Dewdney Creek Group, sandstone, shale minor conglomerate (mainly marine): LOWER AND MIDDLE JURASSIC Ladner Group, sandstone, shale (marine)
UPPER TRIASSIC AND JURASSIC
uTrJs: Cultus Formation, shale, sandstone (marine)
UPPER TRIASSIC
uTrn: Nicola Group, basalt and andesite (commonly fragmental), limestone, argillite (marine)
TRIASSIC (?)
TR?vs: Bowen Island Group, greenstone, minor sedimentary rocks
PENNSYLVANIAN (?) PERMIAN (?), AND MIDDLE TRIASSIC
PPTRf: Ferguson Group and PPTRh: Hozameen Group: greenstone chert, limestone, shale and metamorphic equivalents (marine
PENNSYLVANIAN AND PERMIAN
PPcc: Cache Creek Group, greenstone, limestone, chert, argillite, lithic sandstone, PPc: Chilliwack Group, greenstone, limestone, argillite, sandstone (mainly marine)
GRANITIC ROCKS
MIOCENE AND EARLIER
Tgr: Chilliwack, Needle Peak and Hell's Gate Plutons, granodiorite and quartz diorite
UPPER JURASSIC OR LOWER CRETACEOUS
JKgr: Mount Lytton Batholith or Eagle Granodiorite, granodiorite, quartz diorite and diorite, commonly foliated
UPPER TRIASSIC OR LOWER JURASSIC
TRgr: Guichon Batholith, granodiorite and quartz diorite
AGE VARIED, MAINLY CRETACEOUS
ugr: granodiorite, quartz diorite, local syenite
ULTRAMAFIC ROCKS
PERMO-TRIASSIC (?)
Sp: Serpentinite
METAMORPHIC ROCKS
AGE UNCERTAIN
Um: low to medium grade phyllite, schist, amphibolite, migmatite
Gn: gneiss, may include pre-Devonian and possibly Precambrian
Geological contact
Fault
Thrust Fault (teeth on upthrust side)
Excursion Route - Highway
11-7
Excursion stops listed by day i.e. Day No. 11 Stop No. 7
122°
121°
120°
51°
50°
49°
123°
CACHE CREEK
11-8
11-7
11-6
KAMLOOPS
SPENCES BRIDGE
12-1
12-2
LYTTON
12-3
12-4
BOSTON BAR
12-5
YALE
12-6
HOPE
12-7
VANCOUVER
Fraser River
Thompson River
North Thompson River
Kamloops L.
Harrison Lake
Pitt L.
Stave L.
Howe Sound
Burrard Inlet
Strait of Georgia
Figure 1
GEOLOGICAL MAP OF PART OF SOUTHWESTERN CANADIAN CORDILLERA
Map compiled by R.B. Campbell, 1971
Sources: Modified from Guidebook for Southwestern British Columbia
Dept. of Geology, Univ. of B.C., Report No.6
Cockfield, 1948
Duffell and McTaggart, 1952
Monger, 1970
Rice, 1947
Roddick, 1965
10 0 10 20 MILES
10 0 10 20 30 40 KILOMETRES

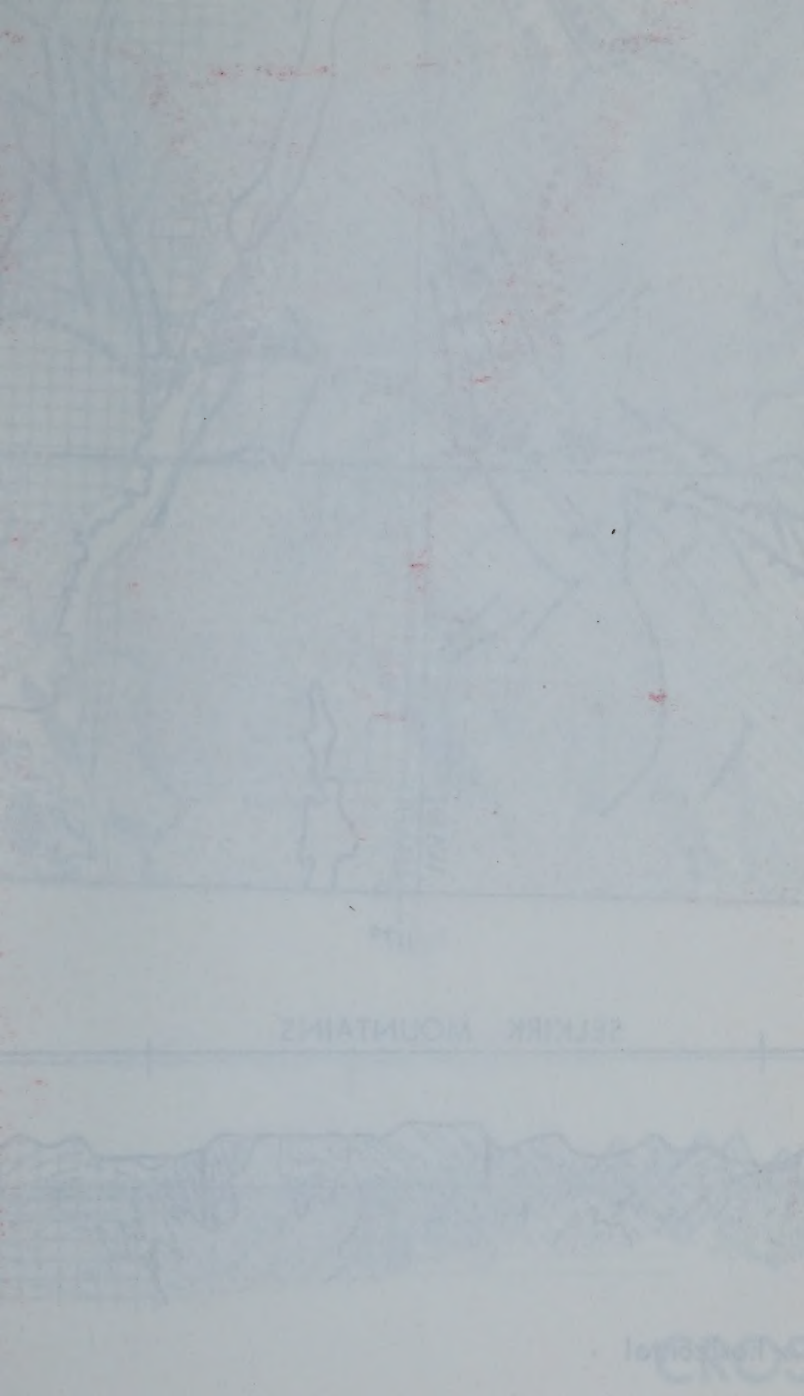
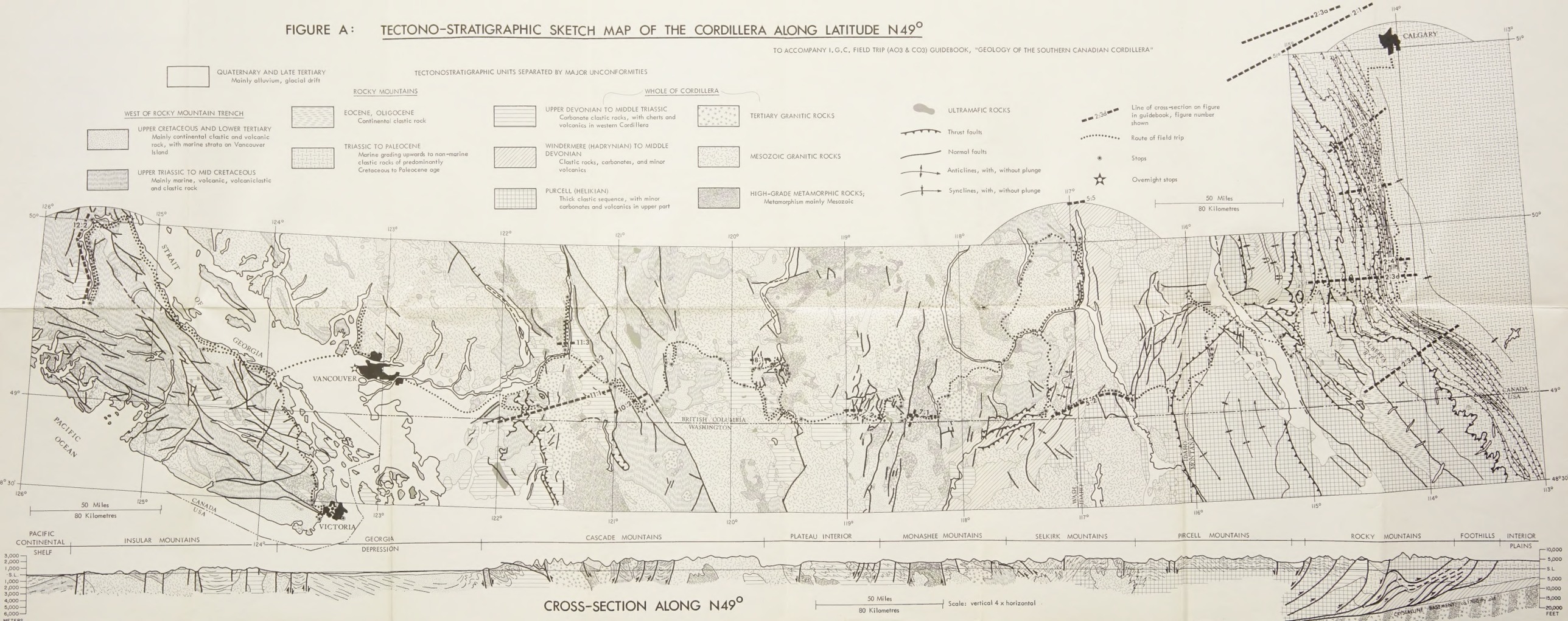


FIGURE A: TECTONO-STRATIGRAPHIC SKETCH MAP OF THE CORDILLERA ALONG LATITUDE N49°

TO ACCOMPANY I.G.C. FIELD TRIP (AO3 & CO3) GUIDEBOOK, "GEOLOGY OF THE SOUTHERN CANADIAN CORDILLERA"



CROSS-SECTION ALONG N49°

50 Miles
80 Kilometres

Scale: vertical 4 x horizontal

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557.1IN82F C001 V003
FIELD EXCURSONS A-C OTTAWA
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